JULY 1955

THE WELDING JOURNAL

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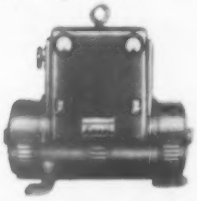

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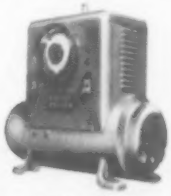

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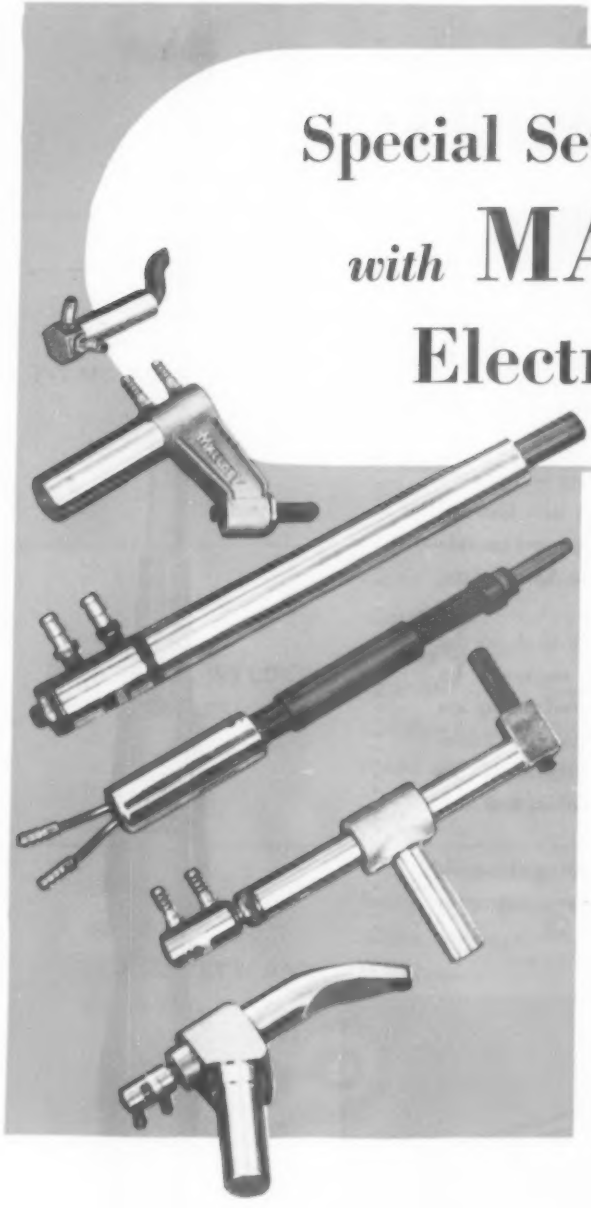

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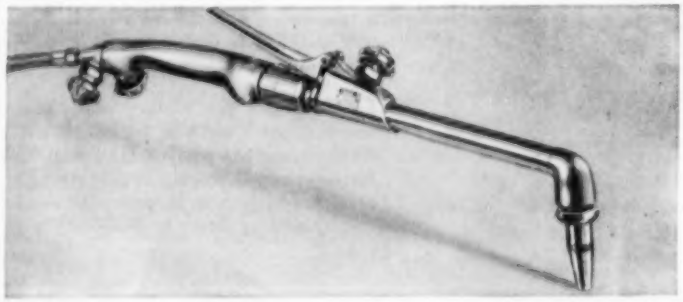

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EDITORIAL

BROADENING HORIZONS

The development of welding has been explosive. Only thirty-seven years have passed since the French built at Caen an entirely welded ship. Although not more than sixty-six feet long, the Bureau Veritas and Lloyd's Register gave this small ship a one-year certificate. It was in service for thirty-two years. In 1944, an enormous fleet of welded ships arrived at Caen.

It was only 25 years ago that the first all-welded stainless steel pressure vessel was built. By 1955, a complete chemical industry had grown on welding, particularly the welding of stainless steel. Welding has progressed so far and so quickly that, by today, man's ingenuity has devised machines which are almost unthinkable without welded construction—for example, the jet engine. Welding has been the greatest aid to productivity yet devised.

During these years, we have all been so occupied with pressing and immediate problems in our own countries and, indeed, frequently in our own backyards, that there has scarcely been time for a broader look at welding the world over.

The close of the last world war offered this challenging opportunity for the first time through creation of the International Institute of Welding. Slow to start because of the necessity for bringing welding knowledge to some common level before progress can be realized, the International Institute of Welding has provided an outstanding medium for the exchange of views and knowledge so necessary if we are to keep abreast of the rising tide of technology throughout the world. To implement this desirable exchange, groups of overseas peoples have visited our American industry. In 1955, for the first time, a small American group will return these visits through the recently established American Council to the International Institute of Welding—joint instrumentality of the AMERICAN WELDING SOCIETY, the Welding Research Council and the Ship Structure Committee. Now we find these bodies really extending the services to American industry which they were created to fulfill. As a result, all those interested in welding are now being kept up to date, not only on developments at home as heretofore, but on developments throughout the World. Let us progress and learn!

Surely, this is a happy sign of Broadening Horizons.

Howard Biers
PRESIDENT
INTERNATIONAL INSTITUTE OF WELDING

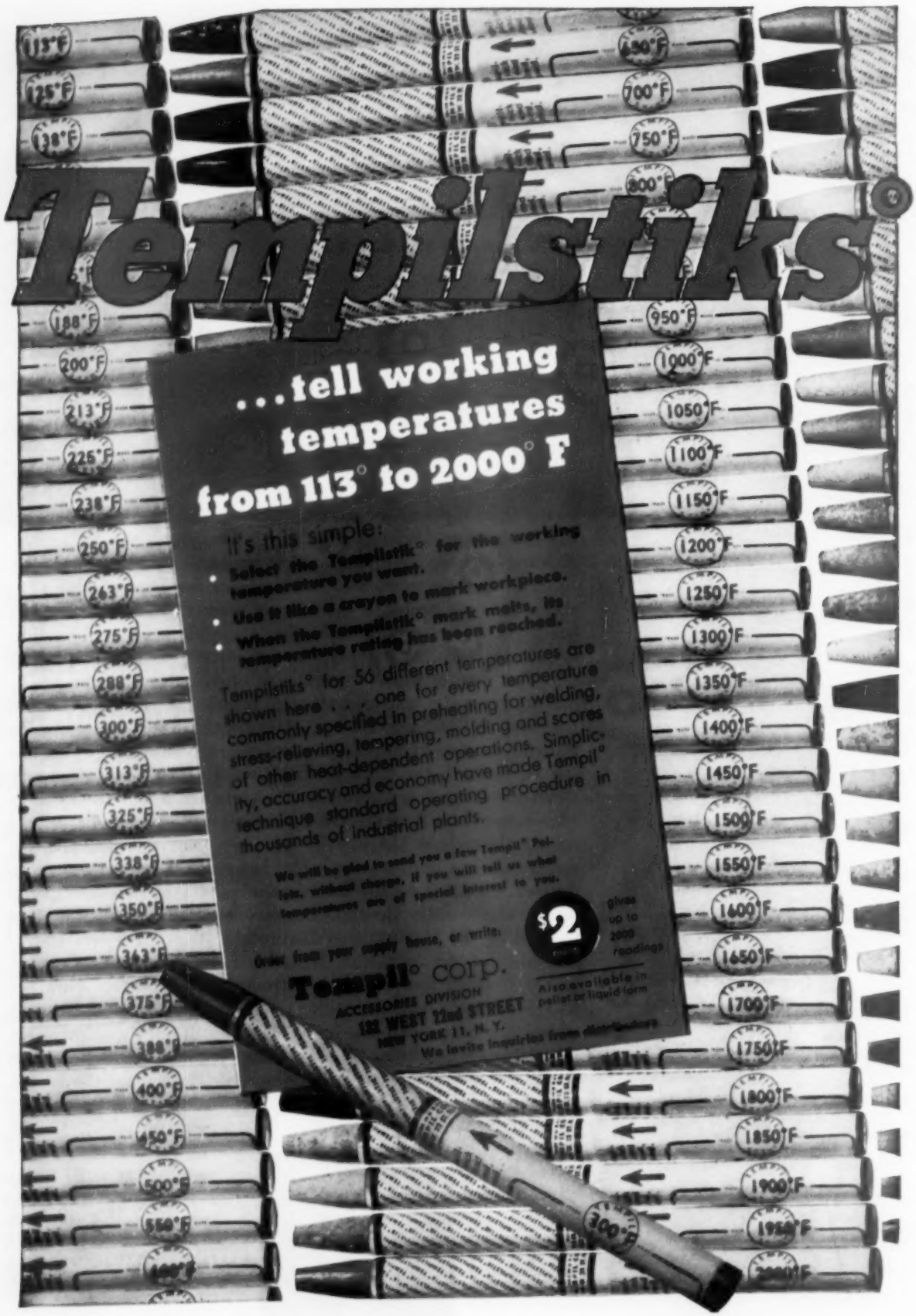
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Fig. 1 Inert-gas welding of stainless steel

INERT-GAS WELDING IN THE AIRCRAFT INDUSTRY

Author outlines several applications of inert-gas welding of aluminum, magnesium, titanium and stainless steel

BY J. M. THOMPSON, JR.

SYNOPSIS. This paper discusses the inert-gas welding of aluminum, magnesium, titanium and stainless steel aircraft parts. Applications of inert-gas-shielded arc welding and use of consumable electrodes especially in the field of titanium welding are presented. Various other applications of inert gases in the industry as well as uses for atomic hydrogen welding are mentioned. A series of photographs show various jigs and fixtures and some of the typical parts that are manufactured by inert-gas welding process.

J. M. Thompson, Jr., is Supervisor, Process Control, Convair, a Division of General Dynamics Corp., Fort Worth, Tex.

Presented at 1955 AWS National Spring Meeting held in Kansas City, Mo., June 7-10, 1955.

This topic is a very broad one due to the increasing practical application of scientific principles that were until recently regarded as laws of physics and only of academic interest. Since the most recent developments are of a restricted nature, the author will outline briefly some of the generally known applications of inert-gas welding. Some of the other applications of inert gas that we have developed in the aircraft industry will also be shown.

The inert-gas-shielded arc-welding process is used extensively in the welding of aluminum, magnesium,

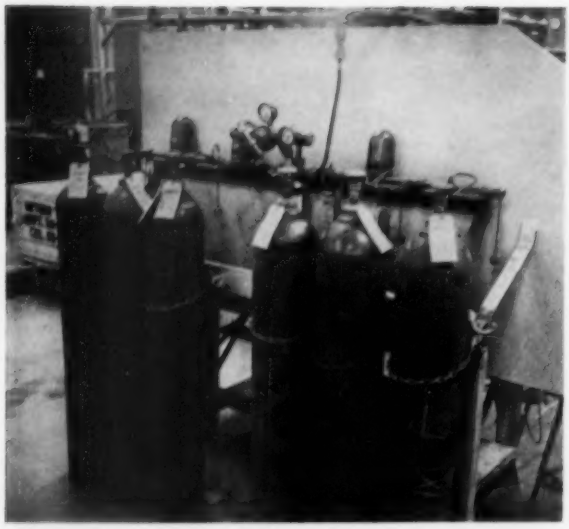


Fig. 2 Argon gas manifolding system

Fig. 3 Heliarc welding on aluminum assembly

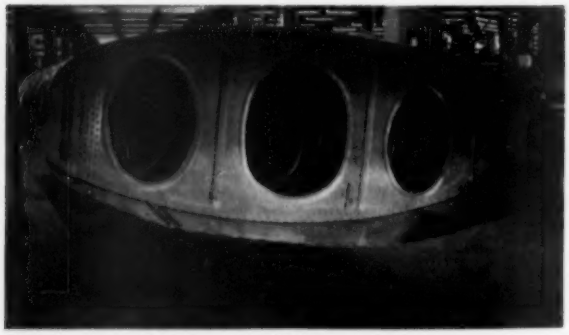


Fig. 4 Aircraft structure in fuel storage tank

titanium and stainless steel aircraft parts. This process, which originally used helium as the inert gas shield, is familiar to most readers. However, it has been found that argon is much more satisfactory than helium due to the shielding effect afforded by its greater density. Some aircraft factories are using helium and argon mixtures usually in the ratio of one part helium to three parts argon. The following illustrations will show some of the current applications of inert-gas welding.

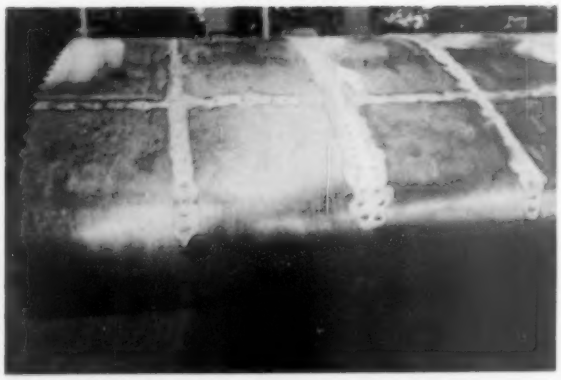


Fig. 5 Gastight welding of aluminum rivet heads

Fig. 6 Scallop weld joints in fuel storage tank

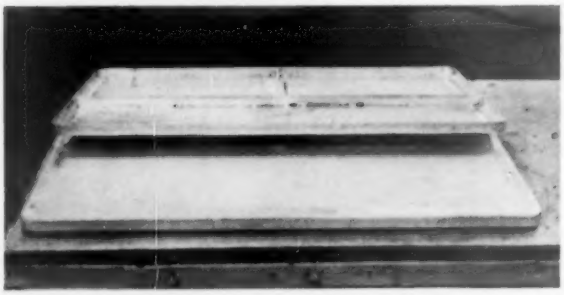


Fig. 7 Welded magnesium instrument panels

Figure 2 shows the manifold system used to furnish a constant pressure supply of argon gas to a battery of inert-gas tungsten-arc welding booths, one of which can be seen in the background. A line pressure of approximately 20 psi is maintained in the system from three cylinders at all times. The cylinders are used and changed in banks of three, thus maintaining continuous service and line pressure.

Figure 3 shows a welding operator using the inert-gas manual welding method to join aluminum alloy parts. He is welding a collar machined from 61S aluminum alloy to a 52S aluminum alloy tube. The filler metal, which is 43S aluminum alloy, is being fed manually into the weld by the operator.

Figure 4 is an end view of a large gasoline storage tank. Note the typical, riveted and lightened aircraft bulkhead structure used in its construction.

Figure 5 shows one method used for making the riveted joints leaktight. These 56S aluminum alloy rivet

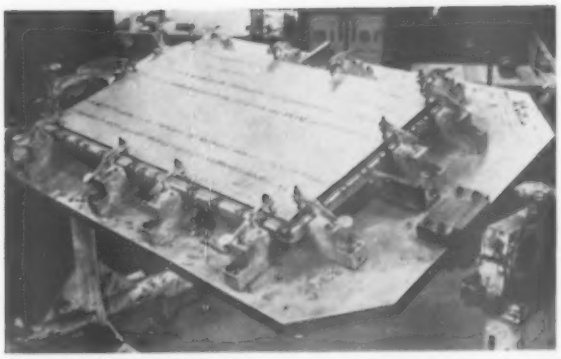


Fig. 8 Welding fixture for magnesium panels

Fig. 9 Checking flatness of part on holding fixture

heads were inert-arc welded to the 52S aluminum alloy skins with 43S alloy rod. One quarter inch diameter rivets were driven and a "skip" welding technique was used to seal the joints. Approximately one-half the circumference of the rivet heads was welded and allowed to cool before the other half was welded in order not to place undue strains on the skins. Note the use of the fish tail scollop joint. This was used to provide greater strength and rigidity in the weld joint.

Figure 6 shows the tank after completion of welding and ready for subsequent pressure testing.

Figure 7 represents a typical welded magnesium aircraft panel. Note how tack welds are used along the reinforcing rib members for rigidity of panel. The finished part at the bottom of the picture has had the excess weld bead removed and contoured to the surface of the panel members by rotary cutters. Note the 100% penetration around the edge of panel on underneath side of top panel.

Figure 8 shows the tooling fixture required to hold this part during the welding of the outer flange. It is also required during the tack welding operation. The fixture has access holes for performing the tack welding in place. Note the rollover type portable table. The quick action clamps are practically invaluable in our plant's welding department.

Figure 9 is another view showing the part placed in the welding fixture after completion. This part has had the weld bead ground off and has been stress relieved at 600° F in another fixture to relieve weld stresses. Although correct tooling and welding sequence are essential, some distortion is expected and stress relieving helps obtain proper flatness.

The lead illustration, or Fig. 1, shows an operator preparing to weld a stainless steel part. The extra rubber hoses shown serve to maintain a constant flow of inert gas into the interior of the part in addition to furnishing exterior protection through the torch head. This precaut'on prevents internal oxidation of the part and helps increase welding speed. Strips of tape cover the drilled holes in the part and permit complete coverage by the inert gas. This method of weld protection was developed as a result of our titanium welding program.

The next five illustrations show some of the detail parts that were fabricated from commercially pure titanium. All of these parts were secondary structure and were used in the fire extinguishing system, for cowling support brackets, etc. These parts replaced 321 or 347 stainless steel and some 4130 chrome molybdenum steel tubing. The welding of these titanium parts presented numerous problems since titanium has a definite affinity to absorb oxygen, hydrogen and nitrogen from the atmosphere at elevated temperatures and, since these gases have an embrittling effect, inert gas shielding during welding was mandatory. Due to the many different configurations of weld assemblies, the problems of shielding the weldment and heat-affected zones were very challenging. Assemblies had to be given individual consideration as to methods of introducing inert gas to adequately shield all heat-affected zones as well as the weldments themselves. Most tooling fixtures had to be changed to permit points of entry for inert gas into tubular structures and sometimes small chambers or voids were created for adequate inert gas coverage on heat-affected zones.

The actual welding of titanium required a welding technique very similar to that used for stainless steel. Therefore, personnel who excelled in the welding of stainless steel were selected to weld titanium. These men were given instructions and then were required to practice welding for approximately ten hours on commercially pure scrap titanium of different gages before being permitted to weld production parts.

Alternating-current welding machines were used originally in the welding of titanium. However, through trial and error, it was found that the d-c machine and straight polarity produced a more stable arc due to the low thermal conductivity of titanium.

A $^1/_{32}$-in. diam. tungsten electrode was employed for almost all applications of welding. Due to the small diameter of the electrode, the arc was less erratic permitting the operator to produce more uniform welds and to weld in almost inaccessible areas. A standard No. 6 ceramic cup was found to be of no value since the opening was too small to permit an adequate flow of inert gas to shield the weldment. A No. 10 cup with a $^9/_{16}$-in. opening proved very satisfactory and was used

Fig. 10 Welded titanium assembly

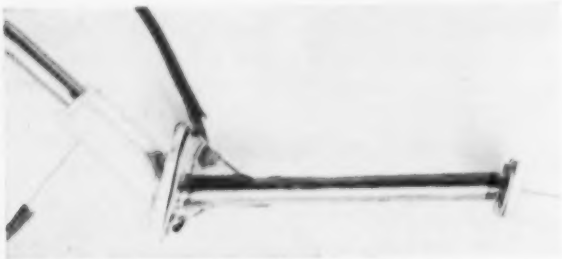


Fig. 11 Inert gas welding chamber for titanium

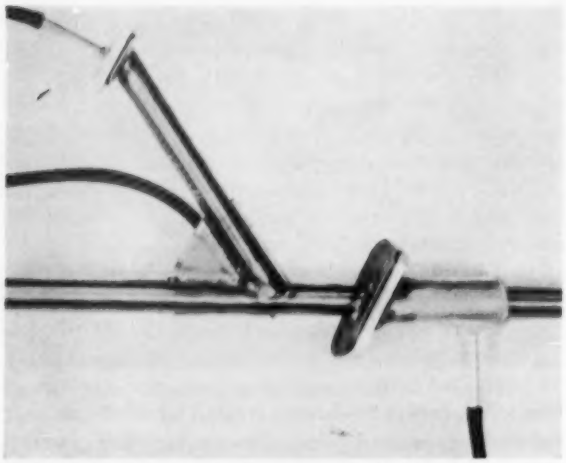


Fig. 12 Inert gas protective measures for titanium

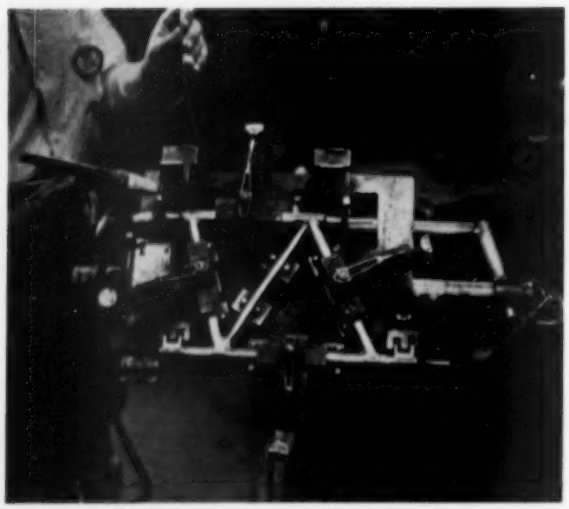


Fig. 13 Welding fixture for titanium assembly

Fig. 14 Typical titanium aircraft assemblies

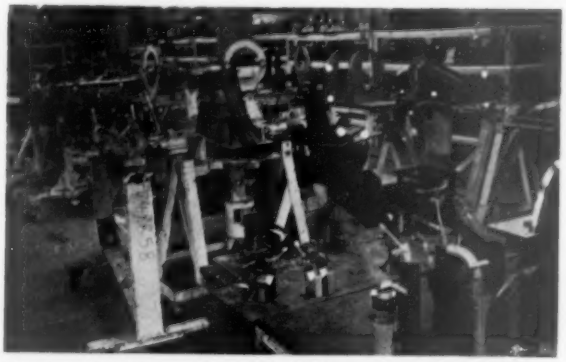


Fig. 15 Typical welding fixtures for aircraft assemblies

for all welding.

Figure 10 shows a part of the fire extinguisher system made of commercially pure titanium. Note again the strips of tape on the prefabricated holes and the method of flowing inert gas into the entire tubular system. Note also the fixture in back of the heat-affected zone which helps prevent oxidation and absorption of harmful gases.

Figure 11 shows another titanium part on which it was necessary to tool a void or chamber for adequate inert gas coverage on the heat-affected zones during welding. Due to the intricate design of the tube and flange joint, the inert gas coverage in tubeless structure alone was insufficient.

Figure 12 shows the use of typical tooling fixtures for purging the heat-affected zones and the tubes simultaneously while welding.

Figure 13 again shows a titanium part in the welding jig being flooded with inert gas. In a tubular structure of this type, all tubes are interdrilled to permit complete flow of argon gas throughout entire structure. Note the plugs in ends of tubes with approximately $^1/_4$-in. diam. tubes extending out. These plugs are drilled with small diameter holes which restrict the direct flow of inert gas being expelled and thus provides adequate coverage. In tubular joints of this type excessive flow of inert gas is very critical because of the

Fig. 16 Pipes brazed with inert gas shielding

Fig. 17 Quick cutoff controls for brazing honeycomb panels

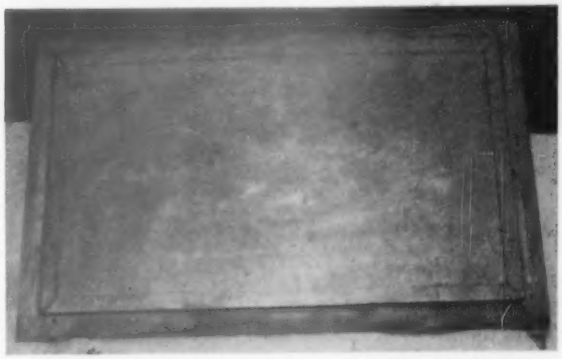


Fig. 18 Brazed stainless steel honeycomb panel

possibility of "arc blow." A 0.010-in. "fit-up" gap between joints is very desirable; however, it is very hard to obtain in ordinary shop production.

Figure 14 shows some of the typical titanium parts that were welded in the test program. To date, the field and service inspection reports of our company indicate that none of the welded assemblies have failed. This is very encouraging since most of the parts are subjected to high-cycle fatigue loads.

As has been indicated in the previous illustrations, a large number of tooling fixtures are required to weld

Fig. 19 Atomic hydrogen welding on tool steel

these parts to close tolerances. The welding fixtures shown in Fig. 15 are just a few of those that have been used at our plant and are now being stored until they are needed to fill spare parts requirements. High tooling costs are encountered in welding the simplest configuration because of the close tolerances necessary in the fit-up of aircraft assemblies.

Figure 16 shows a part of the hydraulic system of a huge three-dimensional stretcher press that was recently installed in our plant. When the equipment was put in use, it was found that every pipe joint in the system leaked oil with the results that the service pit presented a fire hazard. This leakage is understandable since the stretcher operates at 3000 psi pressure. These joints were brazed to prevent leakage. Since this system contained hydraulic oil and had very close fitting valves, it was decided that inert gas should be purged throughout the system during brazing in order to prevent scaling that might clog or impair the highly sensitive control valves. This, of course, is an exceptional use for inert gas.

Another interesting use of inert gas in aircraft is demonstrated by Fig. 17. The retort contains a stainless steel honeycomb sandwich panel. Here an attempt is being made to copper braze a metallic core to covering skins. In order to do this, a dry hydrogen atmosphere is employed in the electric furnace. As a safety precaution, the part is purged with argon gas before it enters the furnace. During the cooling cycle, the part is again purged with argon gas as a safety precaution as well as to prevent scaling. This is accomplished by the use of a system of quick disconnect valves.

Figure 18 shows a brazed panel; the honeycomb effect of the core material can be seen at a close look. This is typical of very thin skins on the order of 0.005 in. and less.

Figure 19 presents the extreme opposite of inert gas welding. The operator is welding with atomic hydrogen, one of the most active gases known. He is welding an oversize hole in a piece of tool steel with a rod of the same composition. The welding electrode holder holds two tungsten electrodes. As the hydrogen gas flows through the arc, the molecules of hydrogen break down into its atomic form. This gas produces a highly reducing atmosphere over the work and allows very high temperature welding to be accomplished.

Figure 20 shows the atomic hydrogen welding machine, the cylinder of hydrogen and several welding electrode holders in detail.

The author has attempted to show some of the uses of inert gases in different types of welding of aircraft parts at his plant. No doubt, more complicated parts than these are being welded by others and some of the more advanced methods are being used by them. Convair is installing a constant-potential, inert-arc, gas-shielded automatic welding machine on which the welding speed and the feeding of the consumable metal into the weldment will be governed automatically by electronic controls. A constant-potential, consumable electrode, inert-gas-shielded arc-welding machine is being used on some very heavy aluminum weldments. Both of these applications will employ argon as an inert-gas shield.

The continued use of inert gas in the aircraft industry is assured and, as high performance aircraft are developed, new applications of these welding processes will be engineered into their structures.

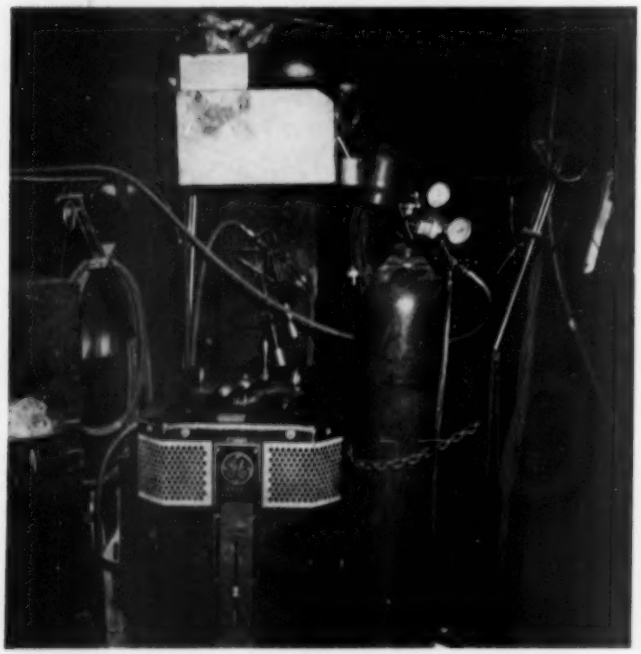


Fig. 20 Atomic hydrogen welding equipment

Correction:

"Recent Developments on Contact Electrodes"

by D. L. Mathias

•

In the April 1955 issue of The Welding Journal, *page 324, column 1, last paragraph, line 2, "Mn/Si" ratio should read Si/Mn ratio.*

The Editor

Hand welding a restraint joint in chrome-steel pipe

HAND WELDING 5-CHROME AND 9-CHROME PIPE

Commonly used welding procedure requires stress relieving immediately after welding. Author describes alternate procedure which produces welds with equivalent properties, but at lower fabrication cost

By W. J. LESTER

ABSTRACT. Weld cracking and hard, brittle zones in 5-chrome and 9-chrome pipe may be overcome by preheating followed by a stress-relief treatment. The welding procedure that is in common use requires stress relieving immediately after welding. This paper describes an alternative procedure that allows cooling from the preheat temperature to ambient conditions after a $^1/_2$-hr postheat at 500° F. Stress relieving follows later at some more convenient time. The use of this procedure produces welds as satisfactory as those immediately stress relieved, but at lower fabrication cost.

Both procedures were investigated under two different levels of restraint—high restraint and low restraint. Mechanical tests in accordance with ASME Code Section IX, impact tests, X-ray, microhardness surveys, and microstructure examinations were made on welded pipe coupons. The results show that both procedures produce essentially the same results—welds that are free of cracks, that meet ASME Code requirements and that have equivalent mechanical properties.

The effect of the $^1/_2$-hr postheat at 500° F was studied. The results show that the postheat acts as a low-temperature tempering operation. It softens the hard martensitic structures in the weld and increases ductility and impact strength. The cumulative result prevents cracking of the weld when it is cooled to ambient temperature prior to stress relief.

W. J. Lester is associated with C. F. Braun & Co., Alhambra, Calif.

Presented at the Ninth Western Metal Congress, Los Angeles, Calif., Mar. 28-Apr. 1, 1955.

Introduction

Oil-refining processes of today often require the use of 5-chrome and 9-chrome alloy-steel piping. The pipe is usually joined in the field by hand welding. Special procedures must be used to prevent cracking and the formation of hard, brittle zones. This paper compares the hand-welding procedure commonly in use with an

alternate method used successfully for several years by our company.

The procedure that is in common use involves three steps. We will call this procedure No. 1. Preheat to a temperature of 400 to 600° F. Weld and maintain the preheat temperature. Then stress relieve at 1325 to 1375° F immediately, without allowing the weld region to cool below the minimum preheat temperature. This procedure produces good welds. But it presents a serious scheduling problem in field welding and increases fabrication cost.

The alternate procedure, No. 2, allows the weld to cool from the preheat temperature to ambient conditions before stress relieving. A preheat of 500° F minimum is used and this temperature is maintained during welding, followed by a postheat at 500° F for $\frac{1}{2}$ hr. The weld is then allowed to cool to atmospheric temperature, and stress relieving at 1325 to 1375° F follows later at some more convenient time. This procedure eliminates the scheduling problem and reduces costs.

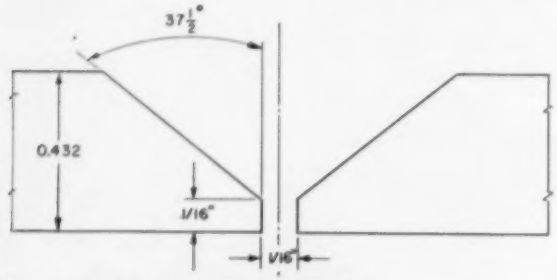
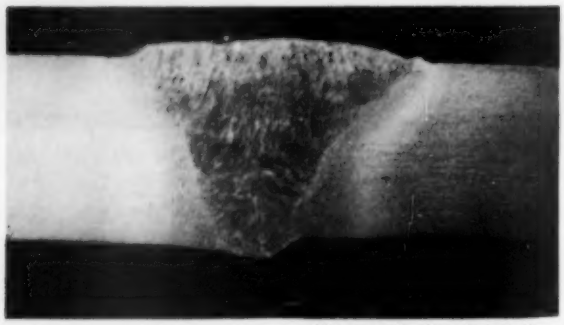


Fig. 1 Joint detail—Schedule 80 pipe



Note microhardness indentations.

Fig. 2 Pipe-weld cross section, 9 chrome steel—procedure 2—restrained. X 3

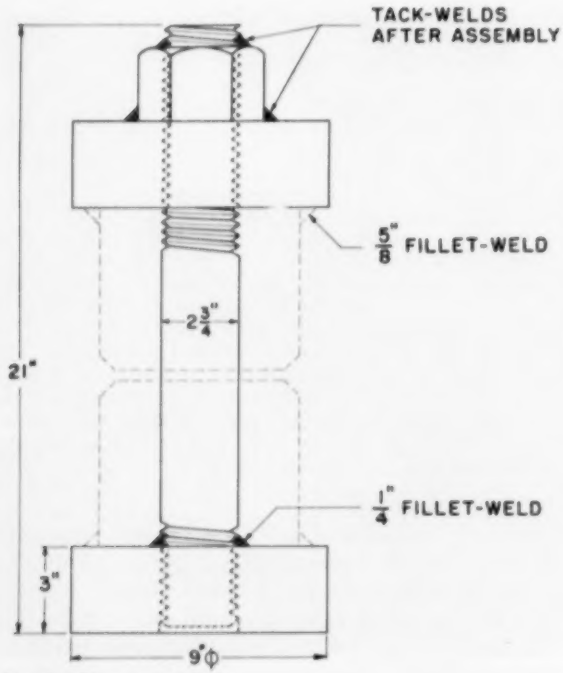


Fig. 3 Pipe restraint jig

Test Work

Both procedures were tested under two different levels of restraint—high restraint and low restraint. A number of joints were welded in 5-chrome and 9-chrome pipe and a comparison was based on the following tests: tensile, bend tests, Charpy impact tests, X-ray, microhardness surveys and microstructure examinations. In addition, the effect of the 500° F postheat on four metallurgical properties—hardness, impact strength, tensile properties and microstructure—was determined.

The welds were made in 6-in., Schedule 80 pipe, purchased to ASTM Specifications A335–P5 and A335–P9. The welding electrodes were AWS E502–15 for the 5-chrome pipe, and Type 505–15 for the 9-chrome pipe, both $\frac{1}{8}$ in. in diameter. Table 1 lists the chemical

Restrained coupon welded in jig

Unrestrained coupon

Fig. 4 Pipe coupons

Table 1—Chemical Analyses

Element %	5-Chrome Pipe	5-Chrome Weld Metal	9-Chrome Pipe	9-Chrome Weld Metal
Carbon	0.10	0.07	0.13	0.08
Manganese	0.29	0.55	0.36	0.38
Phosphorus	0.02	0.02	0.02	0.02
Sulfur	0.001	0.001	0.002	0.004
Silicon	0.38	0.27	0.30	0.27
Chromium	4.91	5.15	8.26	8.93
Molybdenum	0.43	0.37	0.86	0.74

Table 2—ASME Code Tests Pipe Welds

	Tensile strength, psi	
	Specimen 1	Specimen 2
5-Chrome		
Not restrained		
Procedure 1	88,500	88,500
Procedure 2	86,700	87,300
Restrained		
Procedure 1	91,200	90,600
Procedure 2	83,500	82,800
9-Chrome		
Not restrained		
Procedure 1	82,000	82,000
Procedure 2	81,800	80,200
Restrained		
Procedure 1	80,700	81,500
Procedure 2	82,600	82,000

NOTE: All tensile specimens broke in base metal. All root- and face-bend specimens passed.

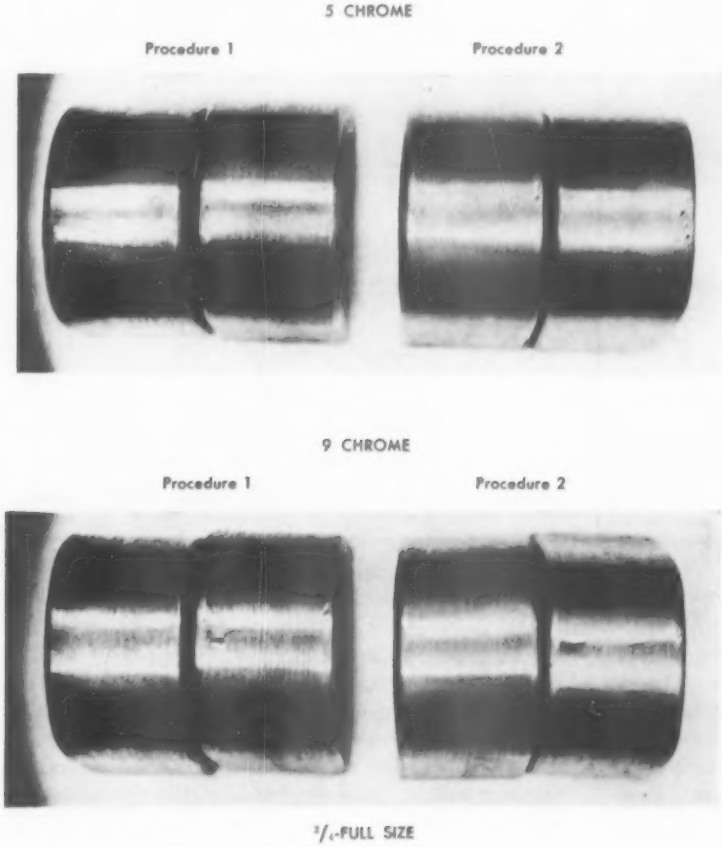


Fig. 5 ASME Code root bends of restrained pipe welds

analyses of these materials.

The pipe bevel was the standard 37 1/2-deg, straight bevel. Figure 1 shows the joint detail. Figure 2 shows a typical weld. The root spacing was 1/16 in. A gas torch was used to preheat the joint to the specified temperature and to maintain this temperature while welding. Commercial temperature indicators were used to indicate the temperature within limits of ±25° F. Postheat and stress-relief treatments were carried out in an electric furnace equipped with automatic controls.

The unrestrained pipe joints were hand welded in the flat position on a welding positioner. One coupon was made for each of the two welding procedures and one for each of the two pipe specifications—four in all. The restrained pipe joints were welded in the horizontal fixed position, and in the vertical fixed position. Figure 3 shows the specially designed jig used to provide high restraint conditions. Figure 4 shows a typical coupon for each condition of restraint.

Two methods were used to determine the effect of postheat: (1) A bead-on-plate method to allow microstructure and hardness studies on the weld, and (2), an isothermal heat treatment method to study the effect on impact strength and tensile properties. The procedure for the bead-on-plate method was to make single weld beads on pieces of 5-chrome and 9-chrome pipe preheated to 500° F ±25 F. Then the pieces were held for various periods of time at a postheat temperature of 500° F, and air cooled. The procedure for the isothermal method was to heat 9-chrome bars, made from the pipe and from weld metal, at 1860° F for 50 min to produce a homogenous austenitic microstructure. Then the bars were quenched in a salt bath at 500° F ±5° F. They were withdrawn after various holding periods, followed by quenching in water to room temperature.

Test Results and Discussion

Table 2 lists the results of the ASME

Table 3—Charpy-Keyhole Impact Tests Pipe Welds

	Impact strength, ft.-lb. 1	2	3	Av.
5-Chrome weld metal				
Not restrained				
Procedure 1	37	30	33	33
Procedure 2	41	35 1/2	42	39
Restrained				
Procedure 1	28	34 1/2	33	32
Procedure 2	32	32	35	33
9-Chrome weld metal				
Not restrained				
Procedure 1	34	29	30	31
Procedure 2	25 1/2	30	31	29
Restrained				
Procedure 1	28	29	32	30
Procedure 2	28	24	33	28

NOTE: Specimens were 1/4 full size.

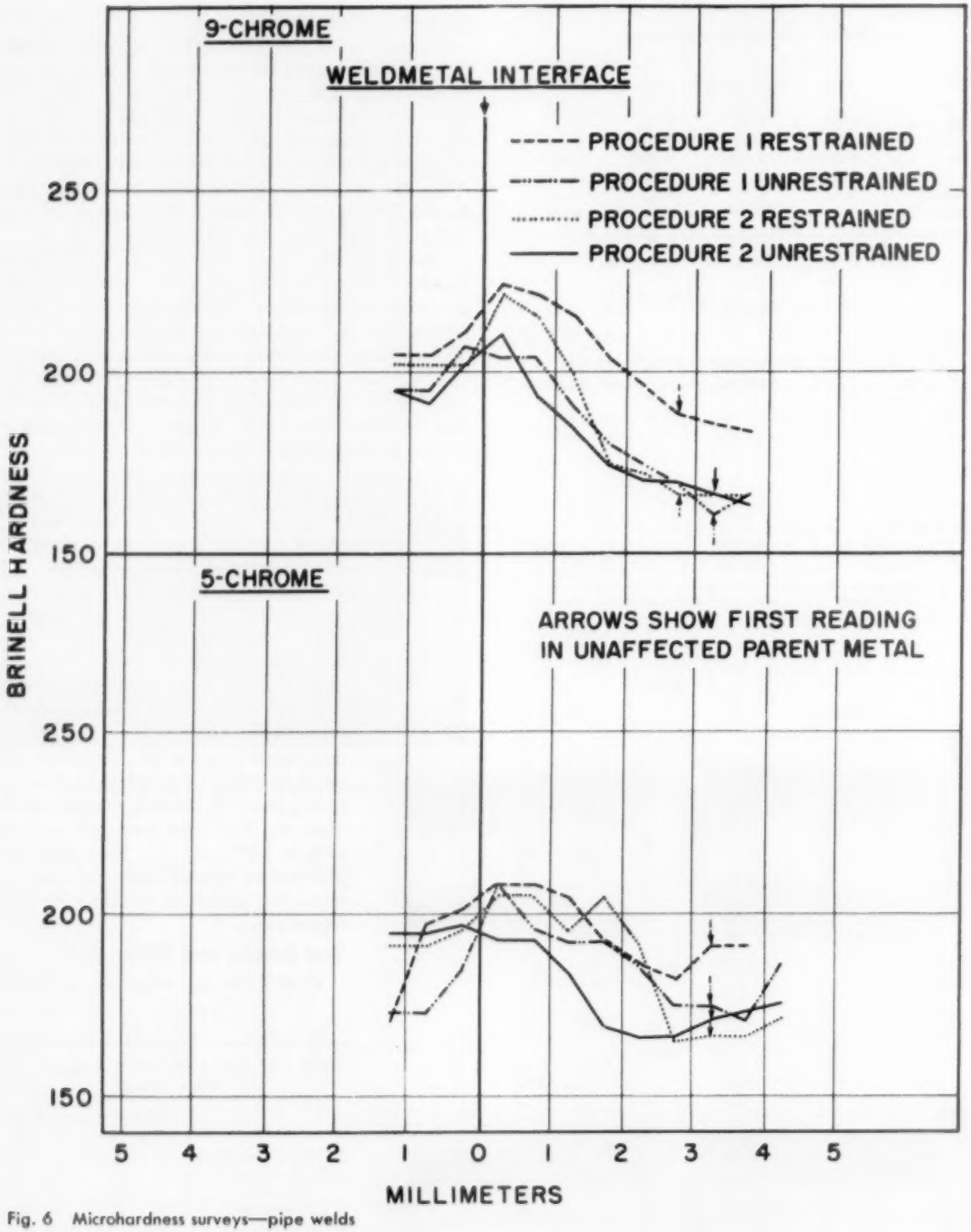


Fig. 6 Microhardness surveys—pipe welds

tensile and bend tests on pipe-weld specimens. All tensile specimens broke in the base metal at values above the specified minimum. The root- and face-bend specimens were all satisfactory. Figure 5 shows typical bend coupons.

Table 3 lists the average of three impact-test results on weld metal from pipe welds. The average result for unrestrained 5-chrome weld metal indicates a preference for Procedure 2. But the scatter of the individual results is as great as the difference shown in the comparison. The conclusion is that the results are equivalent.

The pipe coupons were X-rayed using an oblique technique. And test pieces were X-rayed after being

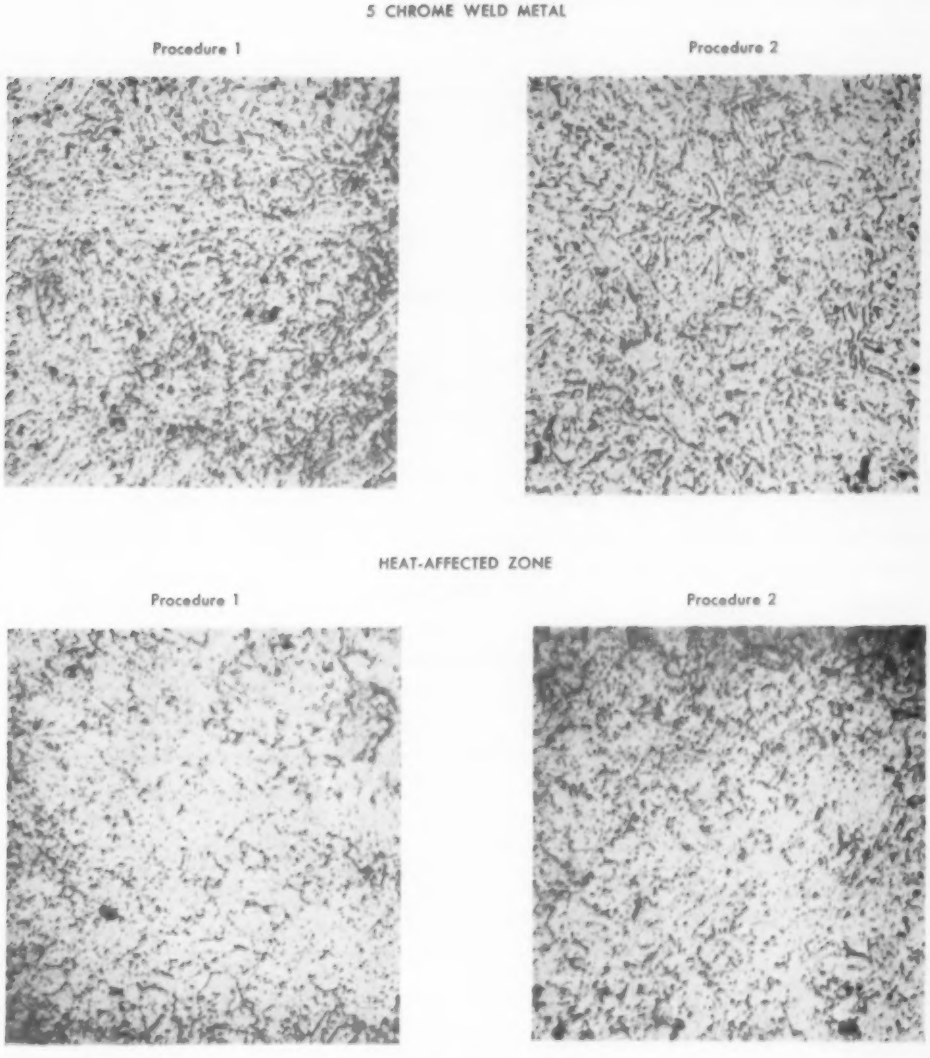


Fig. 7 Microstructures of pipe welds. Magnification, X 500

cut from the pipe coupons. All welds were found to be free of cracks.

The results of the microhardness surveys are plotted in Fig. 6. The interface between the weld metal and the heat-affected zone of the base metal is the reference line. The results show that welds made under high restraint have a higher hardness level than the unrestrained welds. Procedure 1, under conditions of high restraint, tends to produce a higher hardness.

Figure 7 compares the microstructures resulting from each procedure. There is no detectable difference in the microstructure of the weld metal or the heat-affected zone.

The degree of restraint was obtained from strain measurements made during welding in the restraint jig. These measurements record the total contraction of the jig from the start to the finish of the weld. A stress calculation shows that this contraction introduces a stress of about 37,000 psi in the pipe at 500° F. This exceeds the yield strength of the 5-chrome and 9-chrome pipe at this temperature.

Figure 8 is a time-temperature transformation diagram for 5-chrome steel. The time-temperature curves for the two procedures are superimposed on this diagram. The transformation boundaries will be somewhat displaced for welding conditions, but not enough to affect the discussion. Since martensite formation is a temperature-dependent process, the M_s, or point where martensite starts to form, will not change.

During welding, the weld metal and part of the heat-affected zone reach temperatures above the upper critical temperature—A_{c3}. When this metal air cools along the time-temperature lines shown in the diagram, martensite starts to form at about 815° F. At 500° F, the transformation is over 90% complete. And the hardness at room temperature is about 350 Brinell for

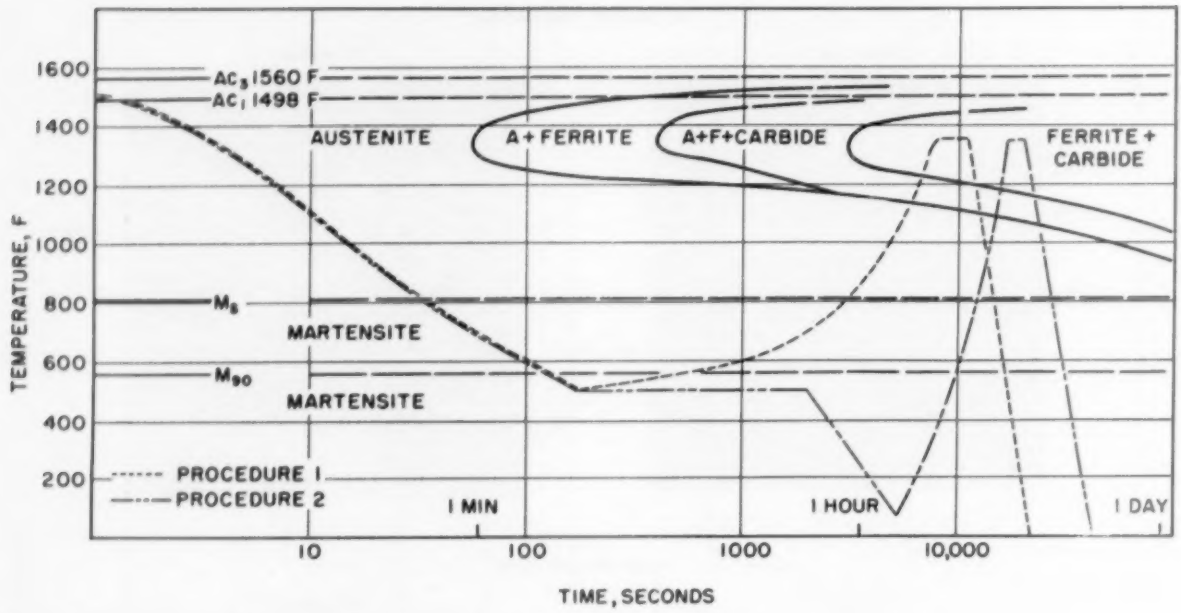


Fig. 8 Time-temperature transformation diagram for 5-Cr, $^1/_2$-Mo, 0.1-C steel with superimposed time-temperature curves for two welding procedures

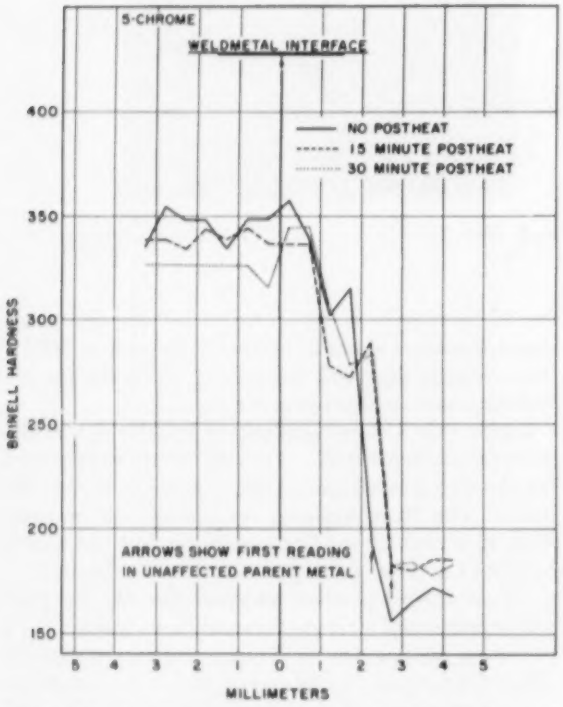


Fig. 9 Microhardness surveys—effect of 500 F postheat on a single-bead weld on 5-chrome steel

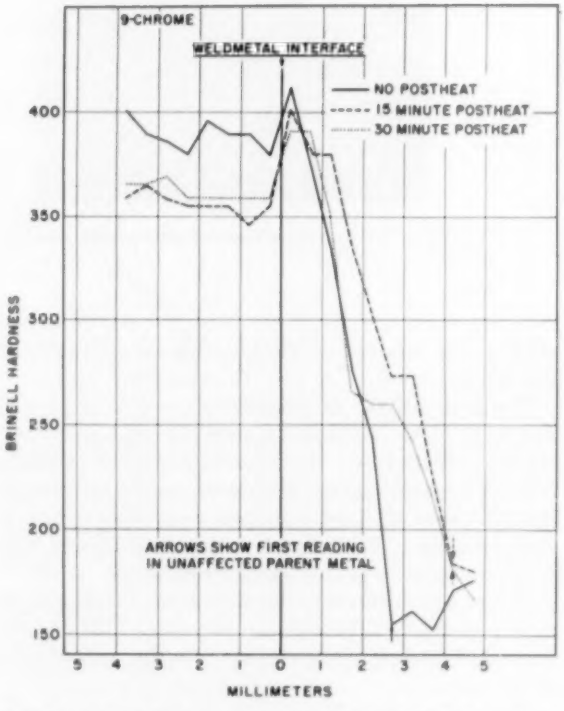


Fig. 10 Microhardness surveys—effect of 500 F postheat on a single-bead weld on 9-chrome steel

the 5-chrome weld, and 400 Brinell for the 9-chrome weld.

The hardness at room temperature decreases when the weld is held at 500° F for $^1/_2$ hr, and then is air cooled. Figures 9 and 10 show the drop in hardness. This softening increases ductility as a result of tempering. In addition, the low-temperature postheat treatment reduces the magnitude of thermal and transformation stresses.

The impact strength increases when the quenched steel is held at 500° F. Table 4 lists the results of the isothermal tests. The specimens were $^3/_4$ full size. Holding for 30 min at 500° F raises the impact strength of the simulated heat-affected zone. This effect is not reflected in the impact properties of the weld metal.

The results of the tensile tests are listed in Table 5. Tensile and yield strength decrease when the quenched steel is held at 500° F for $^1/_2$ hr. Values for elongation and reduction of area increase. These effects of the 500° F postheat result in increased ductility in both the heat-affected zone and the weld metal.

Figure 11 shows the microstructures of the isothermally heat-treated specimens. Under the microscope, it is not possible to detect any changes due to the 500° F postheat.

Conclusions

The results show that both procedures produce welds that have equivalent mechanical properties and microstructures. The welds are free of cracks, and they meet ASME Code requirements.

The postheat for $^1/_2$ hr at 500° F has two effects: (1) it softens the hard regions in the weld and increases ductility, and (2) it increases impact strength of the weld regions. Both effects make the weld more resistant to cracking.

Table 4—Charpy-Keyhole Impact Tests, 500° F Postheat Investigation

	Impact strength, ft-lb				
	1	*2*	*3*		*Av.*
9-Chrome simulated heat-affected zone					
No postheat	23	23	24	24	$23^1/_2$
15-min postheat	$26^1/_2$	$25^1/_2$	26	26	26
30-min postheat	$25^1/_2$	27	27	26	$26^1/_2$
15-hr postheat	28	26	..	..	27
9-Chrome weld metal					
No postheat	13	14	13	14	$13^1/_2$
15-min postheat	14	14	9*	14	14
30-min postheat	13	14	14	14	14
15-hr postheat	17	17	..	..	17

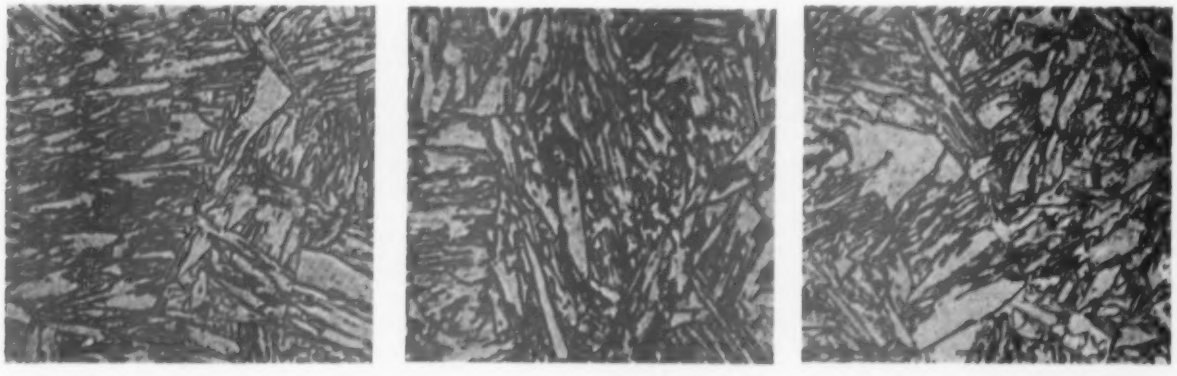
* There was a pinhole in the break.
Specimens were $^3/_4$ full size.

Table 5—Tensile Properties, 500° F Postheat Investigation

	Tensile strength, psi	*Yield strength, psi*	*% elongation in 1-in.*	*Reduction of area, %*
9-Chrome simulated heat-affected zone				
No postheat	197,000	131,000	14	45
15-min postheat	192,000	129,000	13	49
30-min postheat	192,000	125,000	17	51
15-hr postheat	185,000	103,000	18	58
9-Chrome weld metal				
No postheat	181 000	121,000	14	41
15-min postheat	179,500	116,000	14	40
30 min postheat	176,000	108,000	15	46
15 hr postheat	173,000	110,000	17	52

NOTE: The values are the average of results from two tests.

Fig. 11 Microstructures of isothermally heat-treated, 9-chrome steel, Charpy bars. Magnification, X 1000



As-quenched to 500 F | Held at 500 F for 15 min. | Held at 500 F for 30 min.

Arc spot welding of large display cabinet at Falstrom Co., Passaic, N. J. Material is $^{1}/_{16}$-in. steel sheet to $^{3}/_{32}$-in. frame members

INERT-GAS-SHIELDED TUNGSTEN-ARC SPOT WELDING

An investigation of the variables affecting inert-gas-shielded tungsten-arc spot welding. Includes recommended procedures, comparisons with resistance spot welding and job applications

BY C. A. McCLEAN

C. A. McClean is Process Representative, Air Reduction Sales Co., New York.

Presented at the AWS National Spring Meeting held in Buffalo, N. Y., May 4–7, 1954.

Introduction

Inert-gas-shielded tungsten-arc spot welding produces a circular weld between two or more pieces of metal. When the weld is made in a lap joint it can be considered—design wise—in much the same manner as a resistance spot weld. The ability to make such welds in all positions with light, portable, manual equipment working from one side of the joint has greatly facilitated sheet metal fabrication.

An investigation was conducted to determine the effects of the variables on welds made in mild steel and stainless steel. The results obtained made it possible to establish operating data which can be used as a guide in developing procedures for specific applications.

Limited work has been done on other materials such

as copper, Timken 17-22-AS, Nimonic, cast iron, nickel, Monel, Inconel, titanium and zirconium. Future investigations will cover these materials more fully.

For simplification, inert-gas-shielded tungsten-arc spot welding will be referred to as *arc spot welding* in this paper.

Equipment

All of the welding for this investigation was accomplished with the equipment shown in Fig. 1. This specific equipment uses direct current, straight polarity welding power and employs the automatic touch starting method of arc initiation.

The standard unit illustrated in Fig. 1 consists of a manual gun and a control cabinet interconnected with service hoses and electrical leads 25 ft long. The gun is $9^{5}/_{8}$ in. long and weighs approximately 4 lb. Both the gas nozzle assembly and the electrode grip are water cooled. Power is supplied from a standard welding machine capable of providing up to 250 amp with a minimum open-circuit voltage of 55 at required amperage setting. The control circuits operate on 115 v, 60 cycle alternating current. Shielding gas flow rate is metered through a flowmeter regulator and its flow is controlled by a solenoid in the control cabinet. Another solenoid controls cooling water flow.

To make a weld, the nozzle of the gun is placed against the work and the trigger pulled. This starts the flow of cooling water and shielding gas. It also closes a contactor in the control cabinet and advances the electrode to touch the work. The electrode immediately retracts to establish an arc. A weld timer adjustable from 0 to 6 sec opens the welding circuit at the end of a preset time. Another timer controls the length of postweld gas and water flow time.

A second trigger in the forward part of the gun provides built-in arc length adjustment.

The components required for arc spot welding are shown schematically in Fig. 2.

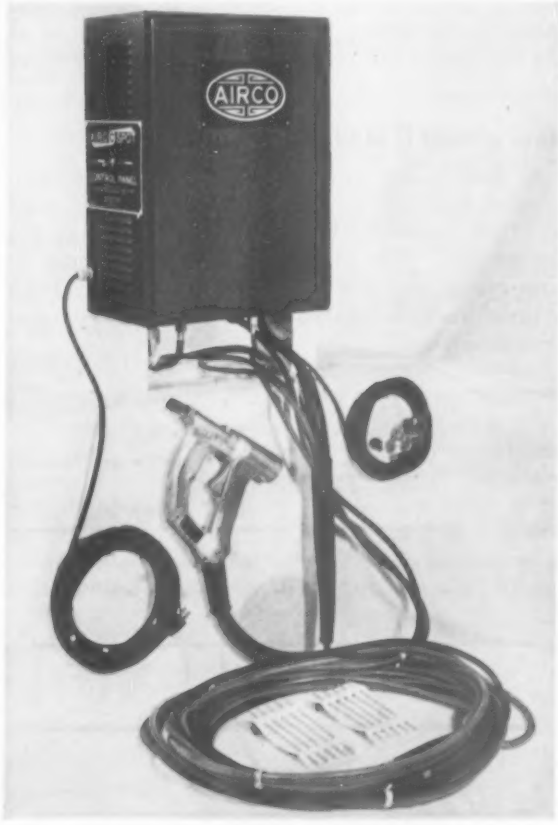


Fig. 1 Arc spot welding unit consisting of manual gun, control cabinet and service connections

Materials

This equipment was designed primarily for steel applications. Therefore this investigation was devoted largely to the welding of mild and stainless steels. All of the fundamentals are discussed as they apply to mild steel. Results on stainless steel are generally comparable and specific differences will be pointed out.

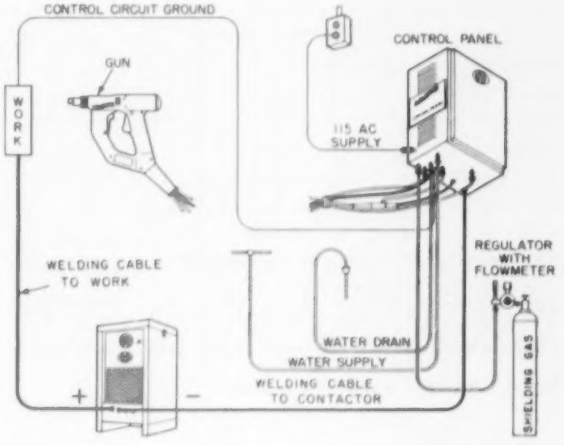


Fig. 2 Schematic diagram of arc spot welding gun and allied equipment

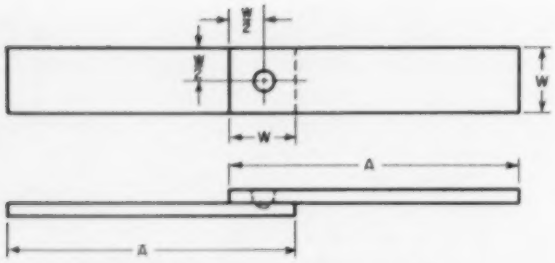
Standards

Because of the many similarities between arc spot welding and resistance spot welding, the resistance spot welding standards and specifications were used as a guide in establishing procedures for arc spot welding and in evaluating results.

Specification MIL-W-6858 appeared to contain the most rigorous requirements and therefore was used as a primary reference.

Test Procedures

One of the fundamental differences between arc spot and resistance spot welding becomes immediately apparent in establishing procedures to be used in developing process data and evaluating results. Because resistance spot welding generally employs two electrodes one on either side of the joint at the point to be welded, the area beneath the weld may be considered to be supported. Arc spot welds are made from one side of



THICKNESS OF THINNER PART	W	A
0.000 - 0.030 INCL	5/8	3
0.031 - 0.050 INCL	1	4
0.051 - 0.125 INCL	1½	5
0.126 & OVER	2	6

Fig. 3 Shear test coupon size as specified in MIL-W-6858

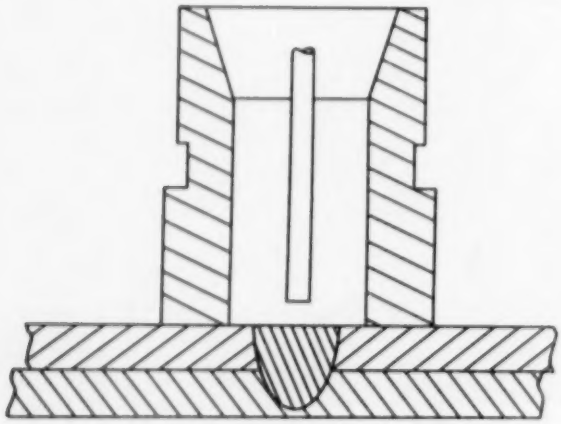


Fig. 4 Arc spot weld cross section

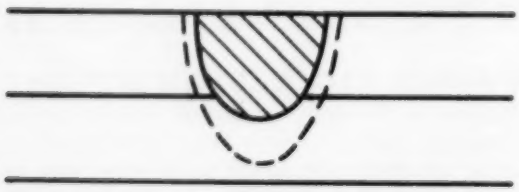


Fig. 5 Net effect of increasing amperage on thin material shown by broken line

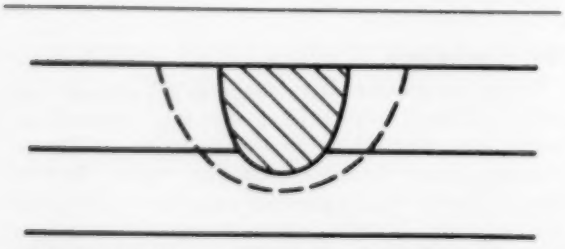


Fig. 6 Net effect of increasing weld time shown by broken line

the joint only and therefore the area directly beneath the spot to be welded may or may not be supported. This will depend upon the thickness, size and shape of the parts to be joined and the results desired.

A jig was designed to permit welding under conditions simulating supported and unsupported joints, i.e., with and without backing. The jig provides a level surface on which to place the testpieces and a means for aligning them. An opening was provided so that the bottom part could bridge the opening to simulate the condition of welding without backing. To simulate the condition of welding with support directly beneath the area to be welded, a block of backing material was inserted in the opening in the jig.

Coupon size, overlap and edge distance are a function of the material thickness as shown in Fig. 3. When dissimilar thicknesses are joined, overlap and edge distance are based on the thinner material.

In the preliminary work, one variable was studied at a time to determine the practical limits of that factor. Every effort was made to keep all other factors constant.

All welds were loaded in shear, with the joint unrestricted, to obtain the ultimate joint strength in pounds per spot. It was realized that many shops would not have a tensile testing machine and so welds were also checked by means of the peel test.* Coupon size for the peel test is also based on the material thickness as shown in Fig. 3. Welds in the lighter gages should pull a button. Button diameter measured at the base of the button and perpendicular to the direction of peel, should be approximately $\sqrt{T}$.

How a Weld Is Made

To make an arc spot weld, the heat of an inert-gas-shielded tungsten arc applied to the top part† must penetrate completely through the top part and into the bottom part.‡ The weld diameter, see Fig. 4, must be large enough to provide the required strength. Depth of fusion has to be great enough for the joint to develop that strength.

* See AWS Welding Handbook—Third Edition, p. 983.
† The part against which the gun is placed.
‡ The piece to which the top part is joined. In multiple layer joints, the part furthest from the top part.

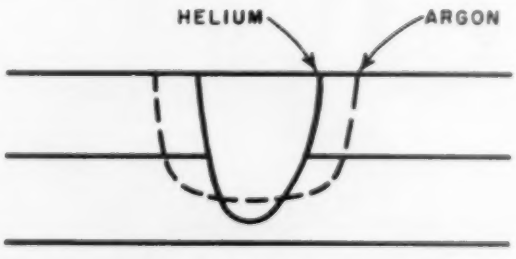


Fig. 7 Comparison of typical weld pattern for helium and argon

The heat to produce a resistance spot weld is obtained from resistance of the work to the flow of electrical current in a circuit of which the work is a part.*

Variables

Each of the factors involved in making an arc spot weld will be discussed on the basis of its effect on a single weld. The effects of these variables on reproducibility under shop conditions are covered under the heading of "Reproducibility."

Amperage

If the two pieces are approximately the same thickness (in the lighter gages), the major effect of increasing the amperage is to increase the depth of fusion. It also produces a slight increase in weld diameter as shown by the broken line in Fig. 5. If the bottom part is considerably heavier than the top part, increasing the amperage will generally increase weld diameter. In the heavier gages (both pieces approximately the same thickness), increasing the amperage will increase the depth of fusion up to a point and further increase in amperage will increase weld diameter.

Weld Time

The major effect of increasing the weld time is to increase the weld diameter. It also produces a slight increase in depth of fusion as shown by the broken line in Fig. 6.

Shielding Gas

Helium will generally produce greater depth of fusion than argon. Argon will generally produce a larger weld diameter than helium as shown in Fig. 7. Helium-argon mixtures in the ratio of two parts helium to one part argon (by volume) generally produce a weld diameter about midway between those obtained with helium and argon. The 2:1 helium-argon mixture has been found to be particularly advantageous for producing high-strength, high-quality welds in the lighter gages. This is particularly noticeable when joining stainless steels.

Shielding Gas Flow

In general, the flow of shielding gas (helium, argon or helium-argon mixtures) should be approximately 6 cfh (2.83 lpm). For some applications, lower flows have proved satisfactory. However, if lower flows are desired to obtain greater economies, tests should be run to prove the suitability of the lower flow on the particular application before it is used in production.

The recommended flow of 6 cfh is based on the use of the equipment under normal shop conditions. If conditions are such that the entire face of the nozzle cannot be brought into contact with the workpiece, higher gas flows will be required. If this condition is encountered on a production operation, manufacture of a special nozzle to match the contour of the parts will generally be more economical than the use of higher gas flows.

Electrode

Because this equipment employs automatic touch starting, use of thoriated tungsten electrodes is recommended. The standard unit, equipped for the use of a $^3/_{32}$-in. diam electrode, is rated at 200 amp. For currents in the range of 200–250 amp, a $^1/_8$-in. diam electrode is recommended.

In general, the end of the electrode should be a flat surface in a plane perpendicular to the axis of the electrode. Maintenance of proper end condition is more critical when working on stainless steel than when working on mild steel. However, it will also be found that a large number of welds can be made on stainless steel before the electrode requires attention.

The end of the electrode will not remain flat and clean as long when working on mild steel as on stainless steel unless the mild steel is clean. However, this does not mean that the electrode requires more frequent attention when welding on mild steel. The end condition is less critical on mild steel. If the end of the electrode has changed considerably after only a few welds have been made, the cause usually is dirty material or use of excessive amperage for the particular application.

For low amperages on extremely thin materials, the end of the electrode should be tapered to a blunt point, or a $^1/_{16}$-in. diam electrode used to prevent the arc from wandering.

Arc Length

It was pointed out that the equipment provides a means for readjusting the arc length to the present amount if it changes as a result of welding. This adjustment can be preset for any arc length up to about $^3/_{16}$ in. However, it has been found that the best results will be obtained on most applications with a $^1/_{16}$-in. arc length. If set for much less than $^1/_{16}$ in., the electrode may freeze to the work. The probability of sticking is greater on dirty material and on hot-rolled steel with mill scale.

Use of arc lengths much greater than $^1/_{16}$ in. will have somewhat the same effect on the weld as a long weld time and a low amperage as shown in Fig. 8. Long arc length also increases the heat-affected zone in the top part, increases heat input to the nozzle and decreases electrode life. It has also been found that excessive arc length will tend to produce radial cracks in the surface of welds made in stainless steels.

Material Composition

In the lighter gages of hot-rolled steel, there appears to be little noticeable difference in the developed strength of welds made in killed and rimmed steel. In

* AWS Welding Handbook, Third Edition, p. 16.

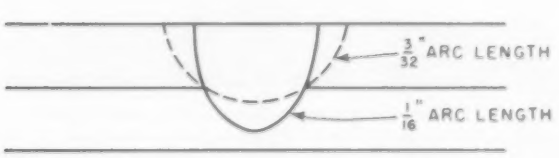


Fig. 8 Net effect of arc length

the heavier sections, killed steel produces better results. In the lighter gages, cold-rolled steel has been found to have better weldability than hot-rolled steel. However, in the heavier sections, cold-rolled steel behaves somewhat like stainless steel in that it can be more difficult to obtain adequate depth of fusion into the bottom part.

Method of Support

If the thickness, size or shape of the bottom part provides sufficient rigidity so that the parts to be joined can be brought into good contact with pressure applied by the gun, backing or jigs generally will not be required. If the bottom part does not have sufficient rigidity to permit the parts to be brought into good contact with pressure applied by the gun, then some means of support must be provided. The method of support will depend upon the parts to be joined. All jigs for the process can be classified under one of two groups.

1. Support is not provided directly beneath the point at which the weld is to be made (support is applied adjacent to or surrounding the location of the weld).
2. Support is provided directly beneath the point at which the weld is made.

If the jigging falls into the Group 1 classification, the net result is much the same as if the rigidity supplied by the jig were inherent in the bottom part. With this type of jig, the same machine settings can be used for all similar joints. It will eliminate the need for changing settings when going from a supported part to an unsupported part of the same thickness. Even though two joints are composed of the same thicknesses of materials, more heat usually will be required for the joint which has backing directly beneath the weld than for the joint in which the area beneath the weld is unsupported.

If the area directly beneath the point to be welded is to be supported (Group 2), steel or copper backing may be used. When steel backing is used (this would be the case when welding on a steel table) the surface condition of the backing and the bottom part must be considered. If these surfaces are clean and the bottom part is relatively thin, excess amperage may produce fusion through the bottom part and the assembly will be welded to the backing. Because of this, copper is recommended as the backing material for joints requiring support beneath the area to be welded.

The copper backing will permit the use of higher heat input without disturbance to the back of the bottom part. Amperage and weld time settings that will cause disturbance of the outer side of the bottom part of unsupported joints, generally will not deface the back of the bottom part when a copper backing is used (see Fig. 9). With a copper backing, stronger welds can be made in the lighter sections. Weld strengths equal to unsupported joints can be made quicker (with higher amperage) because the copper backing has the effect of producing larger weld diameters.

Surface Condition and Surface Contact

Because of the way in which heat is applied, any factor which tends to minimize the amount of heat transfer into the bottom part will reduce depth of fusion into the bottom part and weld diameter and thereby reduce the strength of the joint. Mill scale, oil, grease, dirt, paint and other foreign materials on or between the contacting surfaces will prevent good contact and reduce the strength of the weld. If sheared materials are used, the resultant burr can prevent the making of a good weld if the burr is located in such a way that it prevents good contact between the two parts at the point to be welded.

Welds made in hot-rolled steel with mill scale will usually "puff up" and the surface of the weld will have a shiny, glassy surface. There also may be a slight bump in the center of the weld. This can be attributed to the gases released by the heat of the welding operation but trapped before they can escape.

In many instances it was found that where hot-rolled steel was being used, the material was received pickled and oiled. Satisfactory results usually can be obtained on such material if the oil film is not too heavy. However, if the weld area represents but a small portion of the total surface of the parts, it may be more economical to remove the mill scale by grinding or similar means.

The effect of rust on the surfaces was also investigated. In materials up to about 0.050 in., a light film of rust appears to have only a small effect on weld strength, e.g., rusty, cold-rolled steel (0.048 to 0.048 in.) was welded "as is" and with the rust removed. Joint strengths under both conditions were very close.

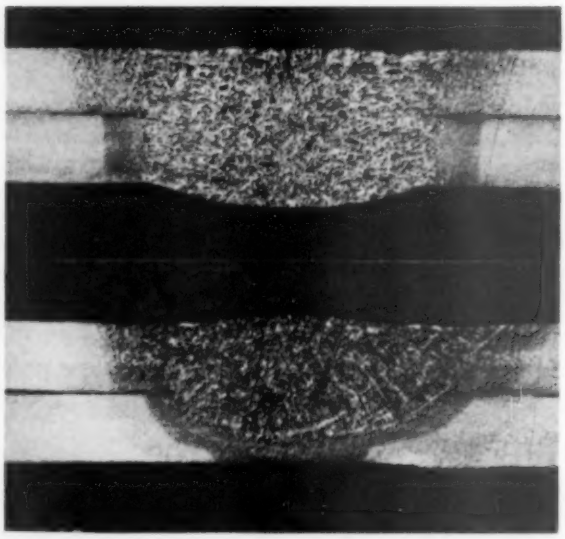


Fig. 9 Effect of copper backing. Both welds made in cold-rolled steel, 0.038 to 0.038 in., He-A mixture, $^{1}/_{16}$-in. arc length, 125 amp, 20 cycles. (*Top*) No backing. (*Bottom*) Copper backing

Mechanical Surface Contact

In some applications, the surface contact between the two parts to be joined may not be good when the parts are placed in position for welding. However, with pressure applied by the gun, the two parts can be brought into sufficiently close contact to permit the making of a good weld. Surface contact is more critical for stainless steel than for mild steel. Stainless steel, 16 gage and heavier, generally requires more applied pressure than mild steel.

In joining light sections to heavy sections, intimacy of surface contact becomes more critical because amperage settings higher than required for joining two light gage parts are usually employed. If contact between the two parts is poor, little or no fusion into the bottom part will be obtained and a hole may be melted through the top part.

On some applications it is difficult to bring the two parts into good contact, even though the top part is relatively thin. This problem usually occurs in the welding of large sheets. Although the sheet may be relatively thin, the size makes it difficult to press it tightly against the bottom part as it is tied down with welds. This is because the periphery of the nozzle rests on relatively cold metal and does not permit the nozzle to force the top part against the bottom part. If the standard nozzle is replaced with the tapered nozzle shown in Fig. 10, better results generally can be obtained. By reducing the area of the nozzle in contact with the work so that the nozzle face presses on relatively hot metal, it is possible to set the top part against the bottom part when the top part heats up during the welding cycle.

Material Stiffness

The stiffness of the material as it is affected by thickness will have an effect on the weld strength obtainable. Arc spot welds are used largely in lap joints which place the weld in shear. As load is increased, rotation occurs. For a given material, under steadily increasing load, rate of rotation decreases as thickness increases. Also, joint strength increases as rotation decreases. As an example of this, a joint of 0.038- to 0.038- in. cold-rolled steel pulled 950 lb. With the same operating conditions, a joint of 0.038- to 0.250- in. cold-rolled steel pulled 1275 lb.

Strength Requirements

Within the limits of the equipment, arc spot welding can equal resistance spot welding strength requirements. As material thickness increases, adjustments can be made to increase joint strength proportionally for thicknesses up to approximately $^1/_{16}$ in. In the thickness range of $^1/_{16}$ to $^3/_{32}$ in., as the maximum weld diameter and depth of penetration obtainable are approached, the joint strength cannot be increased at the same rate, and weld strength levels off at about $^3/_{32}$ in. thickness.

Joint Design

Assemblies generally should be designed to load the weld in shear. Edge distance must be sufficient to prevent the weld from pulling out of the edge of the part at less than required load. Edge distance also affects rotation under load. Increased edge distance generally will tend to produce slightly higher joint strength. Substandard edge distance (less than $W/2$, Fig. 3) generally will tend to reduce joint strength.

Material Thickness

Specific thickness limitations cannot be given without a complete knowledge of all of the factors involved. Under the proper conditions of surface cleanliness and surface contact, steel up to $^1/_8$ in. thickness can be joined to any practical thickness of steel. However, if the surface condition and fit-up are poor, it may be more difficult to join two pieces of $^1/_{16}$-in. steel than it would be to join two pieces of $^1/_8$-in. steel under proper conditions.

Face Diameter and Heat Mark as Indicators

The relationships between the face diameter of the spot, the heat-affected zone and the amperage and weld time settings also were investigated. The surface diameter of the arc spot is not necessarily an indication of the weld size or the strength of the weld. If the back of the weld can be examined, the heat-affected zone on the back of the weld is a far better indication of the extent of penetration and weld size. This can be observed on samples made to establish settings for a production job. Only qualitative data are available

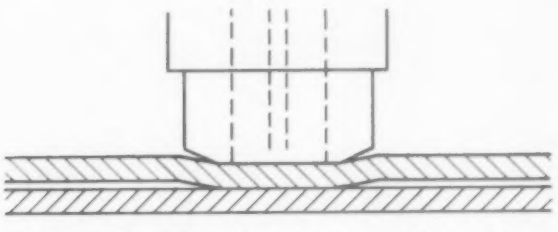


Fig. 10 A tapered nozzle facilitates the joining of large thin sheets to heavier sections

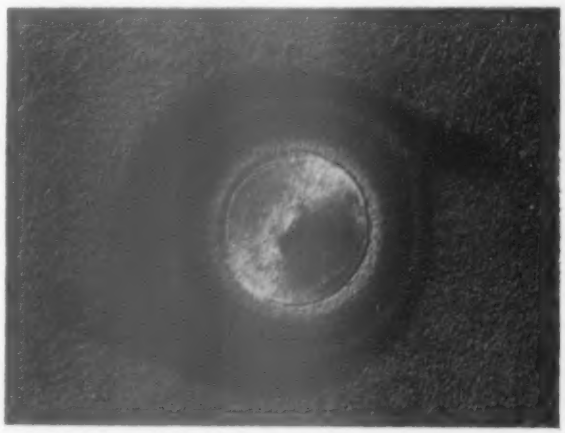


Fig. 11 Arc spot weld with good surface appearance

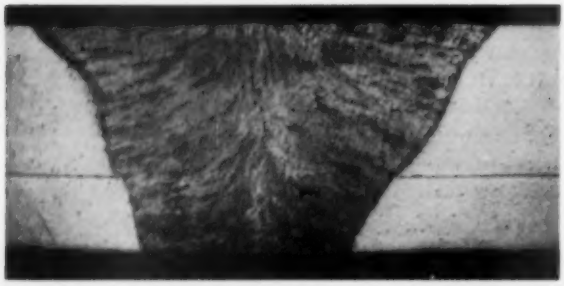


Fig. 12 Macro of arc spot weld made with crater eliminator and controlled gas backing, Type 321 stainless steel, 0.050 to 0.038 in.

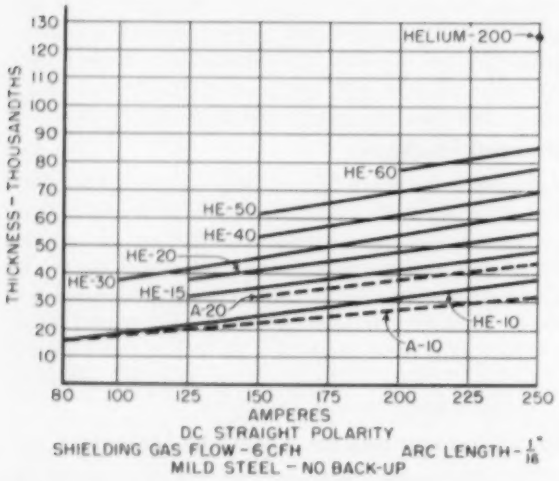


Fig. 13 Operational curves for mild steel

Fig. 14 In addition to the standard nozzle supplied with the gun, other nozzles are available for tack welding: (A) for making tack welds in a corner joint; (B) for making tack welds in a tee joint

because of the many variables which effect the heat zone at the back of the weld.

Other Specification Requirements

For many applications, the contour of the weld surface is not a vital factor. However, techniques have been developed to produce relatively flat welds that will satisfy most requirements (Fig. 11).

Certain light-gage stainless steel parts presented a problem in this respect. Strength and soundness requirements could be met with standard equipment and procedures. However, the slight shrinkage crater produced could not be tolerated. A crater eliminator attachment was developed to correct this condition. This unit automatically inserts a high resistance in the welding circuit at the end of the welding cycle and permits the use of an automatically timed low-amperage arc for postheat. In addition, low-pressure helium backing was employed. With this modified technique, satisfactory welds as shown in Fig. 12 were made.

Weld quality has been mentioned under the various preceding headings. However, there is one factor which deserves specific mention at this point. The zone of highest stress is at the weld periphery. Minor defects at the center of the weld usually have little effect upon the weld strength. Quench cracks, which can occur in the center of the weld, usually have no noticeable effect upon static loading. However, it is believed that they would be detrimental under cyclic stress. (Fatigue data are incomplete at this time.) It has been found that the use of low amperage and long weld time minimizes quench cracking. With the use of a crater eliminator (and copper backing on light sections) arc spot welds without quench cracks can be produced.

Reproducibility

Reproducibility is essential if a tool is to prove useful and practical on a production operation. With this process, it is a function of the degree to which the variables can be controlled. The desired consistency of results dictates the amount of care that must be taken with surface condition, fit-up, etc. The equipment has been found to be capable of producing consistent results equal to the care taken in preparation and operation.

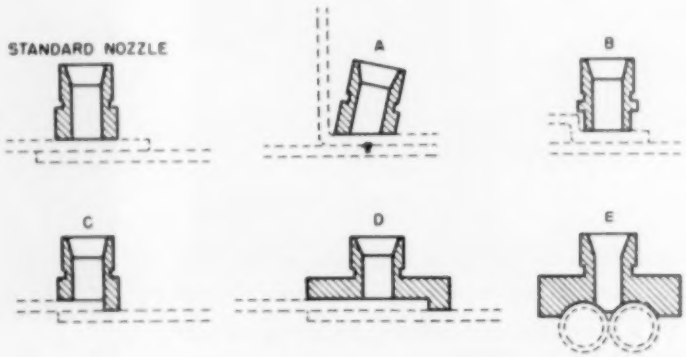


Fig. 15 To provide further flexibility, the standard nozzle can be: (A) machined at an angle to fit into a corner; (B) reduced in diameter for attaching small clips; (C) provided with a step to locate the weld with reference to an edge. Special nozzles can be made D to serve the same purpose as C. Special nozzles can be made E to join parallel tubes. For large diameter tubing, relief is provided to permit the addition of filler metal

1. Amperage—depends upon the power source.

2. Weld time—no variation in weld quality traceable to variation in weld timer.

3. Shielding gas and flow—with proper gas flow control and nozzle held against work properly, no variation traceable to shielding gas.

4. Arc length—a considerable number of welds can be made before readjustment required. A properly trained operator can recognize the need for readjustment.

5. Material—normal mill tolerances do not appear to have an effect.

6. Surface condition—variations in surface condition can have a noticeable effect and the degree of consistency desired dictates the control of surface condition that must be employed.

7. Surface contact—This factor involves the one variable that cannot be calibrated, the operator. However, with proper training he can produce consistent results.

Recommended Settings

A family of weld time curves was plotted for the materials and thickness combinations investigated. These data formed the basis for a chart, Fig. 13, to provide operating conditions which will serve as good starting points in developing settings. These settings are for joining two pieces of the same thickness without backing. If copper backing is used, approximately 10% higher amperage and weld time settings are recommended. For joints in dissimilar thicknesses, settings should be selected according to the thickness of the top part. If the bottom part is thinner than the top part, use less heat; if the bottom part is thicker than the top, use more heat.

Because of the many types of mild steel applications, the data such as those shown in Fig. 13 were plotted primarily on the basis of strength. If a high-speed operation is required, if the back of the weld will not be visible in the finished product and if a slight amount of excess penetration can be tolerated, a high amperage with a short weld time can be used. Other operations will require a low amperage and longer weld time to produce a high-strength weld without obvious disturbance to the surface of the bottom part.

Fig. 16 Arc spot welding used by Twin Coach, Kent, Ohio, as a major assembly tool for attaching steel siding, flooring, internal covering and trim

Fig. 17 Rebuilding stainless steel semitrailer. Material is 22 gage siding and 16 gage frame members

Other Materials

Although this investigation was devoted to mild and stainless steels, a limited amount of time was devoted to other materials. Field data are being assembled for materials such as copper, Timken 17-22-AS, nickel, Monel, Inconel, enameling grade iron, titanium and zirconium. These materials will be covered in future investigations.

Special Nozzles

The copper gas nozzle which is placed in contact with the work can be easily removed and replaced with a special nozzle. A standard nozzle can be modified or a new nozzle can be made to suit specific applications

Fig. 18 Welding 16 gage stainless steel (Type 304) to 11 gage stainless steel frame for meat trays at Glasco, Inc., Paterson, N. J.

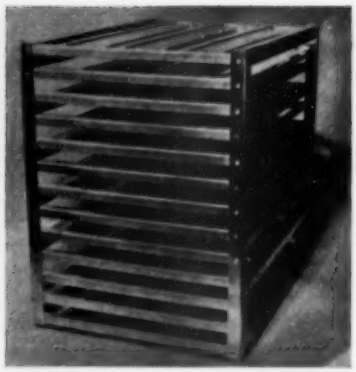


Fig. 19 Stainless steel component for air conditioning unit

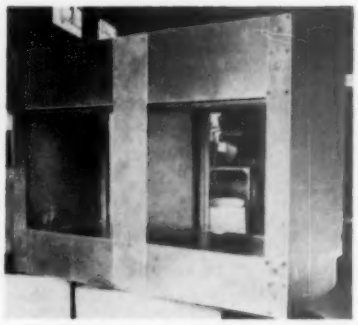


Fig. 20 Production rate of these large cabinets was increased substantially by redesign to take advantage of the arc-spot welding process by Claus Mfg. Co., Cleveland, Ohio

and to provide a built-in jig for locating the weld. Samples of such nozzles are shown in Figs. 14 and 15.

Types of Applications

The many applications for which this equipment is suitable can be divided into two groups on the basis of its use as (1) a primary tool or (2) a secondary tool.

As a primary tool, it can be used in light-gage metal fabrication involving lap joints of the type generally employed in resistance spot welding. These applications usually involve joints which are impractical to resistance spot weld because of location of the weld, size of the parts or the number of welds to be made. Arc spot welding can be used in place of plug welding, riveting and self-tapping screws in assembly and repair applications where its use will speed production by reducing the number of operations. The process also can be used to join parallel tubing and sheet metal to tubing. Because of its versatility and the ease with which it can be adjusted to meet various requirements, arc spot welding should prove valuable in model and prototype shops.

Fig. 21 Tack welding housing of 16 gage mild steel prior to final welding with inert-gas tungsten-arc at Falstrom Co. Passaic, N. J.

As a secondary tool, it can be used for tack welding parts together prior to assembly with other joining methods. Small, uniform welds can be made quickly and thereby minimize or eliminate the need for jigging.

Applications for this equipment are found in the manufacture of such items as: office equipment, furniture, kitchen and restaurant equipment, automobiles, truck and trailer bodies, railroad cars and equipment, tubular members, toys, strapping steel coils in mills and warehouses, aircraft parts, air-conditioning equipment, gear and chain guards, transformer parts, strainer baskets, electrical leads to terminals, attaching brackets and clips, attaching name plates, tack welding—butt, corner, edge, and tee joints.

A number of typical applications are illustrated in Figs. 16 through 21, as well as in the lead photograph.

References

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Placing a titanium sheet within a longitudinal cantilevered hold-down welding stake, in preparation for inert-gas tungsten-arc welding

TITANIUM ALLOY WELDABILITY AND CORRELATED METALLURGY

Extensive test program indicates that alpha and alpha-beta titanium alloys are readily weldable by the inert-gas tungsten-arc process

BY H. L. MEREDITH AND C. W. HANDOVA

ABSTRACT. Two proprietary high-strength titanium alloys were developed for the purpose of finding a weldable material with properties equal to that of the 8% manganese titanium alloy.

The 8% manganese titanium alloy's mechanical properties at 700° F were considered to be good but the alloy's weldability was found to be unsatisfactory.

One of the proprietary alloys was an all-alpha titanium alloy; the second was an alpha-beta titanium alloy.

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RC-A110-AT is the experimental designation given to the alpha alloy. Its alpha stabilizing elements are aluminum and tin.

RS-110-BX is the experimental designation given to the alpha-beta alloy. Manganese is the beta stabilizer and aluminum the alpha stabilizer.

Both alloys have been found to be readily weldable by the inert-gas-shielded nonconsumable tungsten electrode process. The weldability of these two proprietary alloys was determined by several types of tests. The most important tests were weld bend tests, tensile tests and circular patch weld restraint tests.

Weld bend tests showed that the alpha alloy could adjust itself more readily to bending stresses (min bend radius of $5t$) in the as-welded condition than the alpha-beta alloy ($8t$). However, the latter's minimum bend radius could be improved to $4t$ by local torch transformation heating of the weld and heat-affected zone and consequently was considered highly satisfactory for its intended application. In either alloy, welds in square butt joints produced weld joint tensile efficiencies exceeding 100% both at room temperature and 700° F.

The circular patch weld restraint test was used to reflect, in a qualitative manner, the ability of each alloy to withstand residual stresses set up by manual welding procedures and also potential strain aging effects on the alloy and weld so stressed.

The as-received welded alpha-beta alloy was found to be crack sensitive with normal room temperature aging. The circular patch weld restraint specimens developed transverse cracks through the welds approximately four months after welding. However, material which had been vacuum annealed prior to welding did not develop transverse weld cracks after welding. Vacuum annealing is a process used to stabilize the subject material and at the same time remove interstitial hydrogen. Thus by comparing the behavior of the circular patch weld restraint tests on the alpha-beta material it became apparent that excessive interstitial hydrogen causes an unstable condition. This unstable condition gradiently becomes worse with normal room temperature aging and subsequently is likened to strain aging. Actually it is suspicioned to be a gradual diffusion of the hydrogen in the alloy to areas of high stress and subsequently reducing the ductility of the material in these areas.

Vacuum annealing (degassing) of RS-110-BX sheet, which contains hydrogen in excess of 130 p.p.m. (0.013 H_2), has become common practice, in order to render the material more reliable for forming and welding applications.

The as-received alpha alloy was not found to be as crack sensitive as the alpha-beta alloy. Circular patch specimens continue to be crack free six months after welding.

PART I—METALLURGY

Much work on the welding of commercially pure titanium has been done during the last few years and in general it has been accepted as a material which can be joined successfully by welding. Alloy titanium has, on the other hand, been classified as lacking weldability to a large degree. For the purpose of this discussion "weldability" is defined as the capacity of a metal to be fabricated by a prescribed welding process and procedure without undue detriment to its service properties on a given application. Since pure titanium is relatively weak when compared with other available materials, its use is much restricted. Full advantage and large scale usage of titanium will come about only with high-strength titanium alloys, a large part of them of the alpha-beta type. For their broadest use, joining by welding must be successfully accomplished.

North American Aviation, Downey, recognizing the potential usefulness of high-strength titanium alloys for missile application, embarked several years ago upon a large scale titanium alloy welding program. All available commercial titanium alloys plus several experimental alloys were considered. To date we have welding results on a large number of these alloys. Only fusion welding is considered within the scope of this paper.

Preliminary welding studies eliminated and/or narrowed down the number of alloys suitable for welding. An alloy showing some promise in the preliminary tests was subsequently given a comprehensive evaluation as will be shown later on. The approach to the welding study was more of a "scientific" rather than a "cut-and-try" method. All available information such as equilibrium diagrams, chemistry, heat treatment and metallographic analysis was applied. As stated above, it was recognized that certain alpha-beta alloys showed promise. This paper, in the main, will be concerned with a discussion of RS-110-BX.

RS-110-BX, the alpha-beta alloy used in this investigation, is by chemical composition 3.5% manganese, 1.5% aluminum, the balance titanium. The structure of the hot-rolled and stabilized annealed structure is composed of small beta islands in an alpha matrix. The manganese, having low alpha solubility in titanium, and being an alloying element whose equilibrium diagram is of the eutectoid type, results in this alloy having a broad alpha-beta field. Therefore, the RS-110-BX is of a heat treatable nature and sensitive to temperature, time at temperature, cooling rates and aging phenomena. All of these factors are operative in fusion welding. By studying the basic response of an alloy with the use of these variables, its weldability can be predicted. Also, a knowledge of the mechanics of the alloy system involved can be used to determine the welding approach and necessary welding process modification.

Studies of the structures produced by conditions similar to those encountered during welding on the RS-110-BX were made. This alloy on rapid cooling produces an acicular martensitic-like structure called alpha prime (Fig. 1). Tensile tests of specimens quenched to produce this product revealed strengths over 160,000 psi and elongation as low as 2% in a 2-in. gage length. Such a friable structure may, in some cases, be acceptable for design but in general is not looked upon with favor.

Submissive acceptance of this alpha prime structure need not be. Use can be made of the governing equilibrium diagram and time-temperature-transformation curve to alter the structure or produce an entirely different set of constituents.

Figure 2 shows a hypothetical weld cooling rate superimposed on the time-temperature-transformation diagram of a 3% manganese alloy. Theoretically, a weld cooling in such a manner should not produce hard beta since alpha rejection starts at (A) and is complete (B) before the martensitic shear temperature (M_s) is reached. The resultant structure of a weld cooled in this manner should result in complete pro-eutectoid alpha precipitation and high manganese ductile beta.

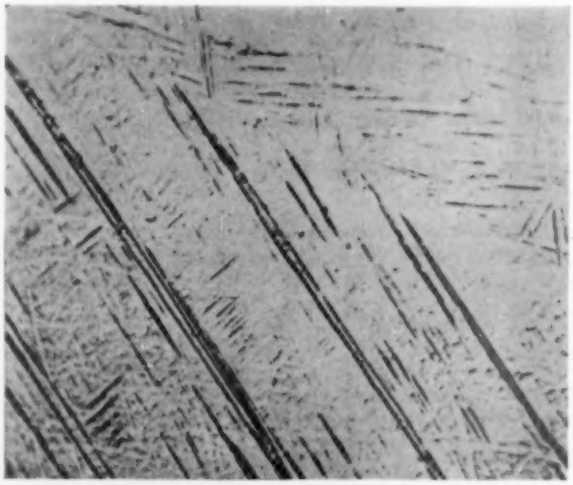


Fig. 1 Acicular alpha prime. X 1000

This structure, while probably acicular in appearance, should have properties approximately equivalent to that of the equiaxed alpha-beta parent material (Fig. 3). Production of welds under such ideal metallurgical conditions may, however, be difficult to accomplish.

Another method, which may be more practical, for increasing weld ductility involves the use of postheat. Locally heating the weld and heat-affected zone after removal of the fast chilling hold-down bars can be beneficial. Resolution of the alpha prime to the beta phase (Fig. 4) and partial decomposition of this phase to alpha under these slower cooling conditions is possible. Even though large quantities of alpha prime may form, the formation of larger discrete alpha needles (with their inherent alpha ductility characteristics), causes the weld to exhibit less brittle qualities. The slower cool may also lend itself to partial aging of the beta above the *Ms* and produce usable ductility. In some cases, where sufficient mass is available to further retard cooling, equiaxed alpha may form at the beta grain boundaries and lend itself to improving ductility.

Using this same approach and heating the structure produced on rapid cooling into the alpha-beta range improve ductility. Times as short as 10 to 20 sec will cause dissociation of part of the beta phase with a marked thickening of the alpha needles. This is shown in Fig. 5. The continuous phase in this photomicrograph, is now further enriched with manganese (the beta stabilizer) by this rejection of alpha titanium to form the Widmanstätten-like orientation. This aids in the over-all ductility of the final structure since the ductility of the high alloy betas is an established fact.

Lastly, and the most obvious treatment, would be to ignore the products formed on welding and heat treat after welding. Due to the complexity of heating thin gage welded structures in this manner, this method is not considered within the scope of this work.

The other alloy discussed in this paper is the alpha alloy 5% aluminum, 2.5% tin, RC-A110-AT. As shown

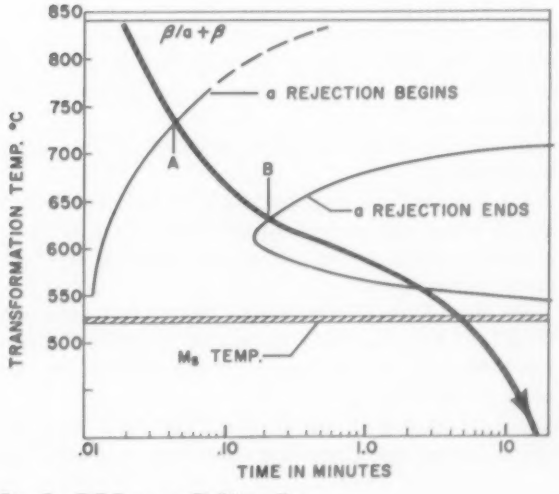


Fig. 2 T-T-T curve, Ti-3Mn alloy

Fig. 3 Equiaxed alpha + beta. X 1000

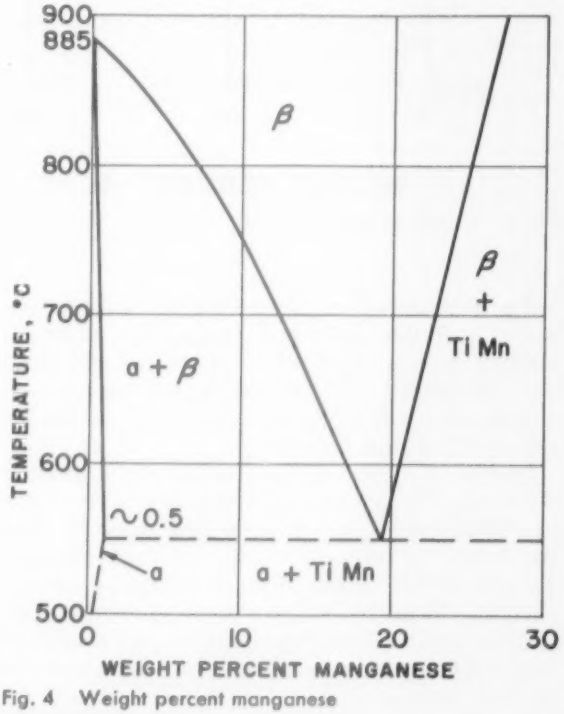


Fig. 4 Weight percent manganese

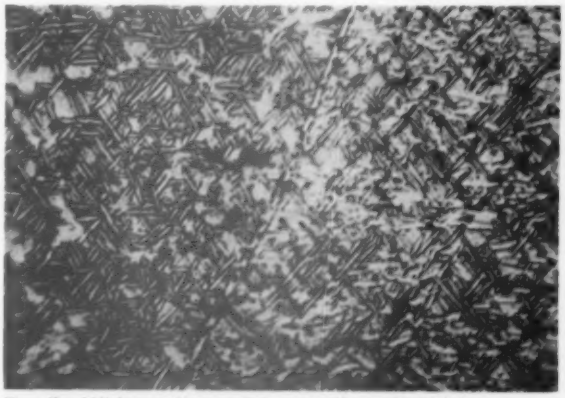


Fig. 5 Widmanstätten alpha needles. X 1000

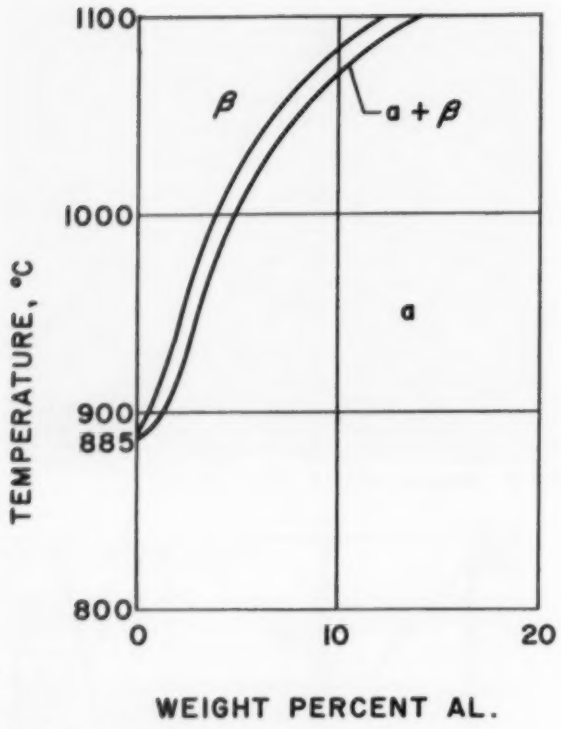


Fig. 6 Weight percent aluminum

in Fig. 6 the alpha-beta field of aluminum alloys is very narrow and the upper beta transus (A) is several hundred degrees higher than that of the alpha-beta alloy RS-110-BX. The M_s temperature has not been determined exactly but would be near 1600° F while the RS-110-BX M_s is about 1000° F.

Because of these conditions, when alpha prime is produced in RC-A110-AT, it is not as amenable to local heat treating methods. Short heating times, 20 to 60 sec, below the alpha-beta field will not sufficiently decompose the alpha prime and increase over-all ductility. As can be seen from the equilibrium diagram for titanium-aluminum alloys containing 6% aluminum, temperatures in excess of 1700° F are needed for entry into the alpha-beta field. Such temperatures could become dangerous from the surface oxidation and surface contamination standpoint.

Again, reheat treatment of structures built of thin gage sheet becomes extremely difficult due to the high temperatures required. However, development of heating techniques for metallurgically changing the properties of the weld area may not be as important on this alloy (RC-A110-AT) as on the RS-110-BX. Comparison of the shear strengths of base and weld metal on both alloys indicates less hardening of the weld metal in the RCA-110-AT. The increase was only 17.5% while the RS-110-BX increased 30.5%. As ductility generally varies inversely with strength, the RS-110-BX weld metal should be less ductile. This can be seen from the bend test data shown later on. This lack of extreme brittleness indicates that titanium alloys producing maximum amounts of alpha prime with minimum amounts of beta upon fairly fast cooling conditions can be welded and have the weld culminate in useful properties.

The above is a brief summary of the metallurgy phenomena occurring during the welding of an alpha and an alpha-beta alloy. The welding engineer confronted with the welding of any titanium or titanium alloy would best understand the problems if he would first investigate the metallurgical functioning of the alloy involved. Recent published articles and private reports will help clarify the reactions involved and explain the structures produced during the welding of titanium.

PART II—WELDABILITY

Weldability Standards

The prime objective of our company's current titanium research and development program is to develop weldable high-strength titanium alloys. As these alloys are progressively developed,* they are surveyed for weldability and formability. The present ultimate weld-joint strength target is set at 80,000 psi at 700° F.

Before an alloy can be considered weldable it must withstand certain tests which simulate service conditions. These tests are called weldability tests. The term weldability and its meaning was touched upon in Part I. It may also be said that a metal is considered ideally weldable if a weld joint in the metal under consideration behaves mechanically the same as a similar piece of unwelded metal. However, for the purpose of screening numerable experimental alloys, the term weldability as used herein is defined as: the degree of ability with which a metal can be fabricated by a preferred joining process without undue detriment to the metal's metallurgical and mechanical properties for an intended application. The preferred process is the inert-gas-shielded nonconsumable tungsten electrode process and the intended application is the fabrication of lightweight airframe structures for use at high temperatures.

On the basis of this definition and with consideration to the requirements established for current airframe applications the following prerequisites were used to establish the minimum acceptable weldability standards.

A titanium alloy shall be considered to have good weldability if:

1. *Tensile Test*—In tensile tests the failures occur in the parent metal away from the weld or the ambient ultimate tensile strength is at least 90% of the base metal tensile strength.

2. *Bend Test*—The minimum 180-deg face bend of a flush butt weld has 50% (in less than 0.062-in. sheet) joint efficiency as compared with base metal minimum bend radius.

3. *Residual Weld Stress Test*—The weld does not crack during normal welding operations and also does

* A coordinated effort between titanium producers, WADC and NAA.

not crack (without additional restraint other than residual stresses set up by normal welding) within a 90 day period.

4. *Mechanical Residual Stress Test*—The weld does not crack in residual circular patch weld restraint tests within 90 days.

5. *Strain Aging Test*—The weld does not crack in stressed circular patch weld restraint tests within 21 days after loading up to the proportional limit.

Scope

The weldability program was divided into three phases. Phase 1 consisted of obtaining fundamental screening information to: (*a*) determine the semiautomatic and manual inert-gas welding characteristics; (*b*) obtain mechanical weld strength and (*c*) obtain weld bendability data for qualitative comparison purposes. Phase 2 consisted of: (*a*) establishing semiautomatic and manual inert-arc welding procedures; (*b*) studying the effect of residual weld stresses; (*c*) studying the effect of strain aging on welds in circular patch weld restraint test specimens and (*d*) determining the minimum weld strength design allowables for use in building airframe structures. Phase 3 consisted of using data obtained from the Phase 1 and 2 tests for designing and constructing various types of low-pressure test tanks and airframe structures.

For the purpose of this report only the technique and test results of the Phase 1 weldability program of two alloys are reported on.

Procedure—Phase 1

Test Specimen Preparation

Test panels, having dimensions as shown in Fig. 7, were power sheared from RS-110-BX and RC-A110-AT standard sheet sizes. Figure 7 is a predetermined layout of the minimum allowable tests used for determining the preliminary weldability characteristics of each alloy tested.

The alpha-beta alloy, RS-110-BX, used for welding tests was from 0.040- and 0.050-in. thick sheet (heat R2A-610), having a ladle analysis of 3.22 Mn, 1.11 Al, 0.073 C, 0.021 N and 0.031 H_2. The sheets received from the mill were in a hot rolled and stabilized anneal condition (1250° F—air cooled) with a reported ultimate tensile strength of 120,200 psi, yield strength of 117,700 psi (set = 0.2%) and elongation of 17% in 2 in.

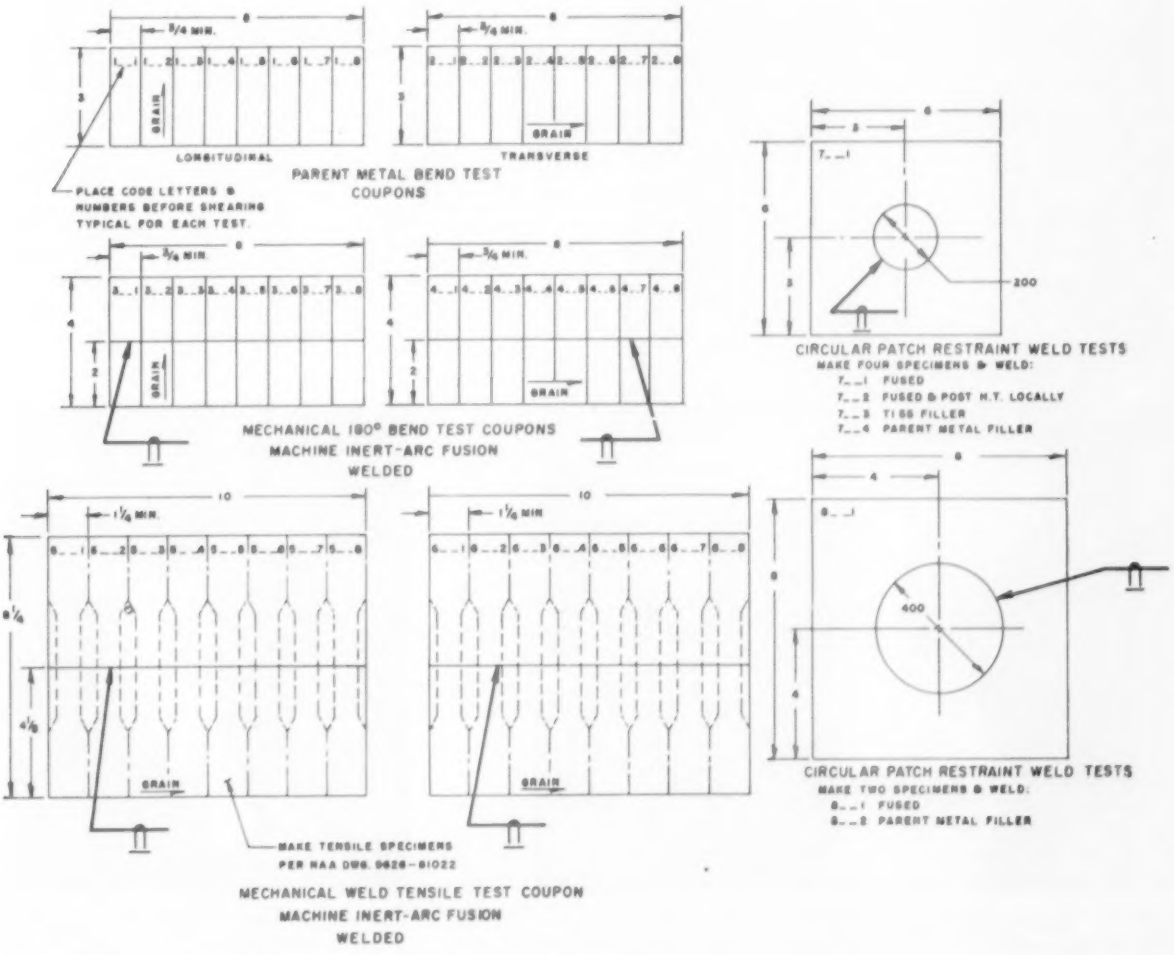
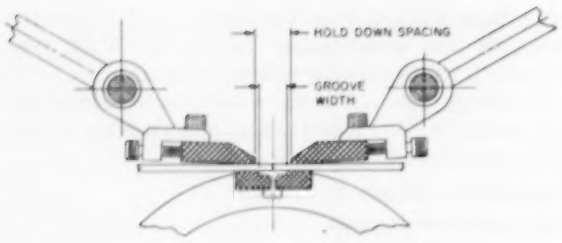

LONGITUDINAL
TRANSVERSE
PARENT METAL BEND TEST COUPONS
PLACE CODE LETTERS & NUMBERS BEFORE SHEARING TYPICAL FOR EACH TEST.
MECHANICAL 180° BEND TEST COUPONS MACHINE INERT-ARC FUSION WELDED
CIRCULAR PATCH RESTRAINT WELD TESTS
MAKE FOUR SPECIMENS @ WELD:
7__1 FUSED
7__2 FUSED & POST H.T. LOCALLY
7__3 Ti 6Al FILLER
7__4 PARENT METAL FILLER
CIRCULAR PATCH RESTRAINT WELD TESTS
MAKE TWO SPECIMENS @ WELD:
8__1 FUSED
8__2 PARENT METAL FILLER
MAKE TENSILE SPECIMENS PER NAA DWG. 9626-81022
MECHANICAL WELD TENSILE TEST COUPON MACHINE INERT-ARC FUSION WELDED

Fig. 7 Phase 1 fusion weldability test layout for titanium alloy sheet



MATL. THICK		.020-.032	.032-.040	.040-.064	.064-.072
GROOVE	WIDTH	3/16	1/4	3/8	5/16
	DEPTH	3/64	3/64	3/64	1/16
HOLD DOWN SPACING		5/16	3/8	1/2	9/16

Fig. 8 Backing bar groove and hold-down spacing dimensions for automatic inert arc welding of titanium

The all-alpha alloy, RC-A110-AT, used was from 0.039-in. thick sheet (heat D31390-2), having a ladle analysis of 4.30 Al, 2.60 Sn, 0.13 C and 0.04 N. The sheets were received from the mill in a hot-rolled and stabilized anneal condition with a reported ultimate tensile strength of 141,500 psi, yield strength of 136,500 psi (set = 0.2%) and elongation of 16.5% in 2 in.

All welds were to be made in square butt groove joints. Exploratory weld tests showed that the addition of filler metal was not necessary because fused welds (no filler metal added) were just as strong as welds with filler metal added. The idea of fuse welding was also considered to be necessary due to the difficulty of readily obtaining weld wire having the same analysis as each different material heat.

Preparation of the square butt joints consisted of power shearing the individual panel halves to rough size. The joint edges were then power belt sanded to remove edge fractures (caused by power shearing) and burrs.

Immediately prior to welding the joint edges were draw filed with very hard brand new mill files. This was done to insure having the cleanest possible joint: using a practical shop tool. Pickling could have been used but it was not considered practical since airframe structures are built in sequences with several weeks of delay between fusion welding operations. If, for any reason the joint edges were handled after draw filing, they were recleaned using acetone solvent.

When welding tests were to be made on vacuum annealed (hydrogen outgassed) material, the test panels were prepared for welding before vacuum annealing. Vacuum annealing consisted of heating the panels to 1300° F in a sealed mild steel retort, holding at heat for approximately four hours at a pressure of 5 microns and then furnace cooled.

Welding

The weld bend and weld tensile test panels were semiautomatically machine inert-arc welded in a 40-in. longitudinal cantilevered hold-down stake. A direct current–straight polarity rectifying alternating-current welding transformer with superimposed high frequency (for easy arc starting) was used. Argon gas was used at the tungsten arc and helium at the weld root. Argon gas was used at the arc in lieu of helium in order to facilitate easy arc starting, and also to minimize the loss of tungsten due to increased arc voltage. Helium was used for backing gas because it was the lighter of the two and seemed to protect the weld root with greater ease at low flowing rates. High flow rates caused the weld root to be concave; subsequently causing an undercut condition at the weld root edges.

Figure 8 is a cross section of the tooling used about the square butt weld joint. The fundamental principles that this type of tooling works on has been found to be the major contributor to successful titanium welding. As can be seen in the cross-section sketch, Fig. 8, air

Fig. 9 (a) Cantilevered hold-down welding stake

Fig. 9 (b) Semiautomatic inert-gas tungsten-arc welding setup for determining weld transformation curves

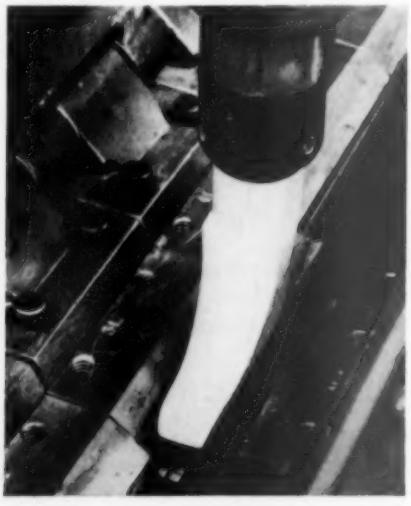


Fig. 9 (c) Special "NOOX" inert-gas-shielding trailer cup

contaminants are readily excluded from the heat-affected areas. The proper selection of backing bar groove width, hold-down toe space and type of shielding cup provides adequate inert gas protection at the weld surface areas. The basic prerequisite of the hold-down toes is to make good metal-to-metal contact with sufficient holding pressure. The metal-to-metal contact helps prevent the aspiration of air from behind the hold-down toe and the hold-down pressure helps to restrain the weld joint and also conduct the heat away, which in turn minimizes distortion and heat-affected zone enlargement.

The hold-down toes and backing bars used were made from hard copper. Copper was not used only for chilling; it was used because it was the only material (mass vs. mass) that would not fuse or readily react with molten titanium.

Several views of the cantilevered hold-down welding stake are shown in Fig. 9.

The welding stake was constructed to use various types of travel carriages and adaptable welding heads. Also included in the stakes construction is a means for adjusting the backing bar mandrel up and down and the copper hold-down feet in and out. For a research welding stake, these adjustments were found to be very important in determining the optimum relationship between hold-down space and backing bar groove width.

In Fig. 9*a* a small inert-gas-cooled vertical and horizontal adjustable welding head is attached to an oxy-acetylene travel carriage. This welding head is used for welding flange joints in thin gage materials. Figure 9*b* shows a more complicated welding head setup. The welding head is also adjusted manually but it is connected to a proprietary electrically operated panel. This particular panel was designed to help simplify weld starting and stopping. Upon pushing a start button the inert gas automatically comes on, a few seconds later the welding arc strikes and then as soon as the maximum current density is established the travel carriage moves at a preselected welding speed. Upon pushing a stop switch, the travel carriage and arc stop simultaneously and then, after a preselected time delay, the inert gas stops flowing. These features are very important because a poor start or stop generally causes embrittlement of the weld, especially so if the inert gas does not pre- or postpurge properly.

Figure 9*c* shows a close-up oblique rear view of a special (no-oxidation) trailer cup used for maintaining an inert-gas-shield at the tungsten arc and also behind the arc over the solidifying weld. The special cup was developed during weldability tests on unalloyed titanium for the purpose of shielding the solidifying weld and heat-affected zone until it cooled to below 900° F. Also seen in Fig. 9*c* are the copper hold-down toes and backing bar.

Circular patch weld restraint specimens were manually inert-gas tungsten-arc welded in a copper plate fixture. The fixture is shown in Fig. 17. A standard water cooled inert-arc welding electrode holder was used with a standard large size shielding cup. Argon gas was employed at the sustained tungsten arc and helium gas at the weld root. A d-c rectifying welder with superimposed high frequency was used. The welding polarity was straight (electrode negative).

Bendability Efficiency

A minimum 180-deg bend radius test was used as a qualitative test for determining whether the weld settings used were producing the most ductile weld. The minimum bend radius of the parent metal was compared with the minimum bend radius of a weld in the same parent metal. For evaluation purposes, a bendability efficiency rating of the weld's minimum bend radius was calculated as follows:

$$\frac{\text{Base metal minimum bend radius}}{\text{Welded metal minimum bend radius}} \times 100 = \text{Percentage of weld bendability}$$

Base Metal Bend Tests

The longitudinal and transverse grain minimum bend radius of each alloy was determined by bending specimens in a 180-deg Di Acro guided-bend test fixture shown in Fig. 10. Fundamentally the test consists of placing a strip of metal $^3/_4$ in. wide next to a round pin

Fig.10 180-deg guided-bend test fixture

of known diameter. A free rolling pin is then snugged up against the opposite side of the strip and pin. The free rolling pin is then pushed about the center pin causing the strip also to bend round the pin.

The first bend was made around an arbitrary pin size. If the specimen did not fail before a 180-deg bend was made then consecutive bends were made with smaller pins until a 180-deg bend was obtained without failure. If the specimen failed in the first bend test, then consecutive bends were made with larger pins until a 180-deg bend was made without failure.

Weld Bend Tests

Bend tests were performed on welded specimens in the same manner that base metal tests were performed. If the weld was made parallel to the grain direction, the specimens produced transverse data. If the weld was

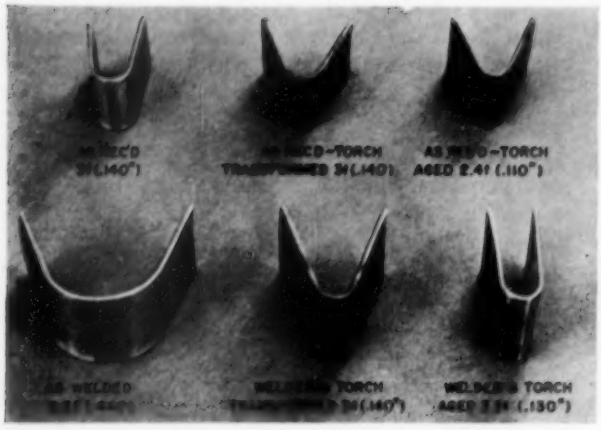


Fig. 11 (a) Minimum bend radius in alpha-beta titanium alloy RS-110-BX, heat R2A-610

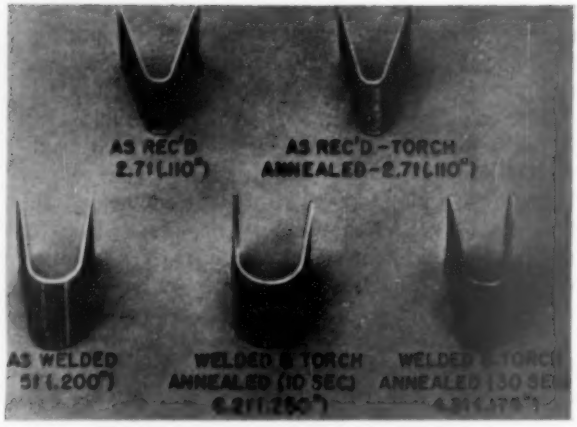


Fig. 11 (b) Minimum bend radius in alpha titanium alloy RC-A110-AT sheet

made perpendicular to the grain direction, the specimens produced longitudinal data. The welded specimens were bent about the center pin with the weld parallel with the pin's axis. The face of the weld (arc side) was placed on the tension side and the root of the weld (drop-through side) was on the compression side next to the center pin. Since the welds were always fused (no filler metal added), the weld bead crest (arc side) never extended more than 0.010 in. above the base metal surface. However, when the weld drop-through (weld root side) exceeded approximately 0.015 in., it was belt sanded until nearly flush with the base metal surface. In this way the welded bend-test specimens had approximately the same physical shape as the base metal specimens.

Torch Transformation

The alpha-beta alloy, RS-110-BX, bend-specimens were welded in the as-received and vacuum annealed condition. The as-received material was in a stabilized heat treated condition having a structure of very fine, elongated beta grains in an alpha matrix. The vacuum annealed material was in a stabilized annealed condition having a structure of coarsened equiaxed beta grains in an alpha matrix.

It was known from physical tests that when the as-received material was reheated above the upper beta transus (1500° F) and then rapidly quenched that a certain amount of the beta phase would exist in the final heat-effected structure as an unstable phase. This unstable phase causes the tensile and yield strengths to increase and is accompanied with a severe loss in ductility.

When welding RS-110-BX sheet in the hold-down stake, shown in Fig. 9, the copper hold-down toes and backing bar caused the weld to be quenched from approximately 3100° F to below 700° F within 3 to 5 sec. The minimum bend radius of $8t$ obtained from bend tests on welds in as-received material reflected the loss of ductility caused by the unstable beta phase.

In order to eliminate this unstable phase it was necessary to reheat the weld and heat-affected zone to slightly above 1250° F and then slowly air cool to below 900° F.

Oxy-acetylene torch heating of the weld and heat-affected zone was used as a qualitative test method for determining whether an embrittled weld could be rendered more ductile by reheating to above the lower beta transus and then air cool.

Several bend specimens were torch heated with a neutral oxy-acetylene flame such that the weld and heat-affected zone would reach a temperature between 1250 and 1500° F within a few seconds. The torch flame was withdrawn slowly after a few seconds of heating and the specimens were then allowed to air cool. This type of heat treatment is termed transformation because the heat-affected material undergoes a structural change which improves the weld and heat-affected zone's ductility.

Summary of Bend Test Results

A definite trend was recognized when the minimum bend radius of the base metal was compared with the minimum bend radius of the welded metal, in each different base metal condition. Table 1 which summarizes the bend results shows that when welds were made in as-received RS-110-BX, a bendability efficiency of 35% was obtained. This is considered unsatisfactory because it shows that the weld is not able to take severe bending stresses. On the other hand when a similar weld was locally heated to 1250° F and air cooled, the bendability efficiency was increased to 100% which is considered excellent because it demonstrates that the weld joint's mechanical bending properties could be made the same as the base metal. The physical difference between the minimum bend radius of the base metal and welded metal is shown in Fig. 11.

When welds were made in vacuum annealed RS-110-BX, a bendability of 75% was obtained. This condition is quite satisfactory for it satisfies the minimum weldability standard's requirements and also eliminates the torch transformation operation. However, local

torch transformation of the weld also improves the welds ductility. A bendability efficiency of 100% can be obtained if necessary.

The bendability efficiency of welds in as-received RC-A110-AT was found to be 56% which also satisfies the minimum bendability efficiency of 50% as required in the weldability standards. The physical difference between the minimum bend radius of the RC-A110-AT base metal and welded metal is shown in Fig. 11.

Tensile Tests

Tensile tests were run on welds, made in square butt joints, at room and 700° F temperatures. The tensile test specimens were standard 8-in. long strips, $^3/_4$ in. wide at the gripping shanks with a necked down 0.500 in. gage width and a corresponding gage length of $2^1/_2$ in.

The RS-110-BX alloy was tensile tested in two different base metal conditions: (1) as-received (hot rolled and stabilized annealed) and (2) vacuum annealed. The RC-A110-AT welds were only tested in the as-welded condition but RS-110-BX was tested in the as-welded and welded and locally torch transformed condition. All tensile test specimens failed outside of the weld and heat affected zone, this is shown in Figs. 12 and 13. The individual test results are shown in Tables 3, 4 and 5 and are summarized in Table 2 and Fig. 14.

Metallographic Investigation

The preceding investigations showed that fusion welds in both alloys have 100% joint strength efficiencies. However, the guided-bend test results revealed that the RS-110-BX weld joint's ductility was impaired in the as-welded condition. Postheating of the welds, by a local oxy-acetylene torch technique, was found to improve the weld ductility in RS-110-BX. The ductility improvement was not very noticeable when the yield strength and percent of elongation of the two conditions were compared but the improvement was very significant when the minimum bend radius of welds in both conditions (one as-welded and the other welded and torch transformed) were compared.

Follow-up tests were made in order to investigate the effect of torch transformation heating on the weld's grain structure. The material used in this follow-up test was in a slightly different stabilized condition (heated for 1 hr at 1230° F and air cooled). Specimens in the as-welded, welded and torch transformed in a welding hold-down stake and welded and torch transformed in air conditions were tensile tested and also

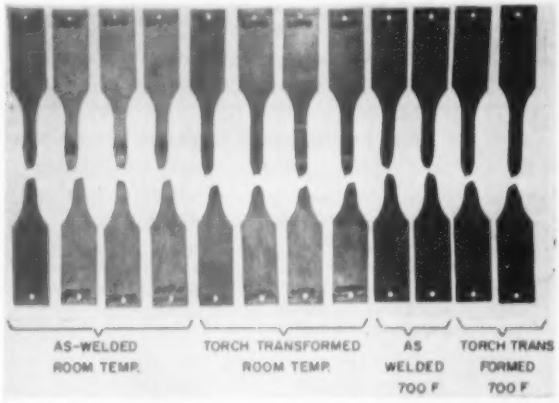


Fig. 12 Tensile test specimens of inert-gas tungsten-arc fusion welds in as-received RS-110-BX

Table I—Minimum Bend Radius Test Results

Material	Base metal condition	Grain direction	Minimum bend radius: Base metal	Minimum bend radius: As-welded	Minimum bend radius: Welded & transformed
RS-110-BX	Stabilized and hot rolled	Transverse	3*t*	8.5*t*	3*t*
RS-110-BX	Vacuum annealed and stabilized	Transverse	3*t*	4*t*	3*t*
RC-A110-AT	Annealed and hot rolled	Transverse	2.8*t*	5*t*	..

Table 2—Summary of Mechanical Properties of Welds in RC-A110-AT and RS-110-BX Titanium Alloy Sheet

Alloy	Test temp., ° F.	Grain direction	Ultimate tensile strength psi	Yield strength psi	% Elongation in 2 in.	Minimum bend radius: Base metal	Minimum bend radius: As-welded	Minimum bend radius: Welded and torch transf.
RS-110-BX[1,*]	Room	T	116,900	112,110	15.0	3*t*	8.5*t*	..
RS-110-BX[2]	Room	T	118,100	111,700	..	3*t*	..	3*t*
RS-110-BX[3]	Room	T	109,700	103,500	12.7	3*t*	4*t*	3*t*
RS-110-BX[1]	700	T	73,900	69,000	15.5	..	..	..
RS-110-BX[2]	700	T	72,600	62,400	..	..	..	..
RS-110-BX[3]	700	T	68,000	54,200	16.6	..	..	..
RC-A110-AT[4]	Room	T	129,400	122,750	10.6	2.8*t*	5*t*	..
RC-A110-AT[4]	Room	L	131,800	117,800	14.0	2.8*t*	5*t*	..
RC-A110-AT[4]	700	T	75,700	59,500	12.0	..	..	..

* Explanation of superior numbers: [1] As-welded; material in hot-rolled and stabilized annealed condition. [2] Welded and locally torch transformed; material in hot-rolled and stabilized annealed condition. [3] As-welded; material in vacuum annealed condition. [4] As-welded; material in hot-rolled and stabilized annealed condition.

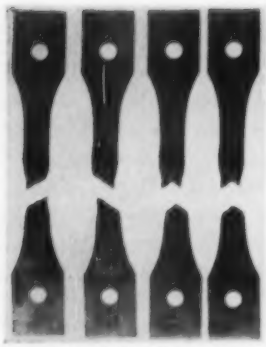


Fig. 13 *(a)* Room temperature 15° interaction tensile test specimens of inert-gas tungsten-arc welds in RC-A110-AT

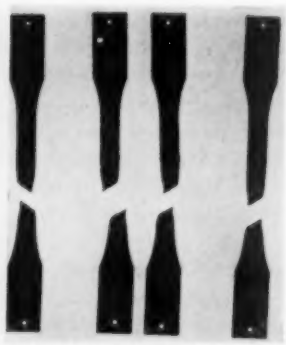


Fig. 13 *(b)* 700 F tensile test specimens of inert-gas tungsten-arc welds in RC-A110-AT

given guided-bend tests. The tensile test results are shown in Table 6.

The guided-bend test results again showed that as-welded specimens could be satisfactorily bent 180 deg around a pin of $8t$ radius with the weld face in tension. When the specimens were torch transformed in air, the minimum bend radius was lowered to $4t$, while the specimens which were postheated in the welding jig had a minimum bend radius of $10t$.

RS-110-BX Discussion

Comparison of the ultimate stress results shown in Table 6 shows that specimens in the as-welded and welded and postheated in hold-down stake condition produced a slightly lower ultimate stress than the specimens which were welded and then postheated in air. This trend is also noticeable in Table 3. Torch heating of welds in the hold-down stake seemed to have a detrimental effect upon the weld's ductility. This test was used in order to determine whether torch heating could be done on welds in the same jig in which the welding was done. The tensile and bend test results

Table 3—Mechanical Properties of Inert-Gas-Shielded Tungsten Arc Fused Square Butt Joint Welds

Specimen Code No.	*Ultimate tensile strength, psi*	*Yield strength, psi*	*% Elongation, in 2 in.*	*Porosity*	*Failure location*
Test Type: Transverse tensile weld joint strength—as-welded Material: RS-110-BX in a hot-rolled and stabilized annealed condition Material Thickness: 0.046 in. Test Temperature: Room					
5UP1	118,400	113,300	15.0	None	
2	116,800	112,100	15.0	None	
3	116,500	112,500	15.0	None	1/2 in. away from weld
4	117,100	111,600	15.0	None	
5	115,900	111,000	15.0	None	
Average	116,900	112,100	15.0		
Test Type: Transverse tensile weld joint strength—Welded and torch transformed Material: RS-110-BX in a hot-rolled and stabilized annealed condition Material Thickness: 0.046 in. Test Temperature: Room					
6UP1	118,400	114,400	*	None	
2	119,600	108,800	*	None	
3	118,300	115,000	*	None	3/4 in. away from weld
4	117,600	112,500	*	None	
5	116,800	107,900	*	None	
Average	118,140	111,720			
Test Type: Transverse tensile weld joint strength—As-welded Material: RS-110-BX in a hot-rolled and stabilized annealed condition Material Thickness: 0.046 in. Test Temperature: 700° F					
5UP6	71,600	58,100	16.0	None	
7	71,200	55,600	16.0	None	
8	77,100	60,800	13.3	None	1/2 in. away from weld
9	75,800	61,400	16.6	None	
Average	73,900	69,000	15.5		
Test Type: Transverse tensile weld joint strength—Welded and torch transformed Material: RS-110-BX in a hot-rolled and stabilized annealed condition Material Thickness: 0.046 in. Test Temperature: 700° F					
6UP6	73,700	64,500	*	None	
7	72,300	60,200	*	None	
8	70,900	60,300	*	None	3/4 in. away from weld
9	73,400	64,500	*	None	
Average	72,600	62,400			

* Failures occured outside the gage length marks.

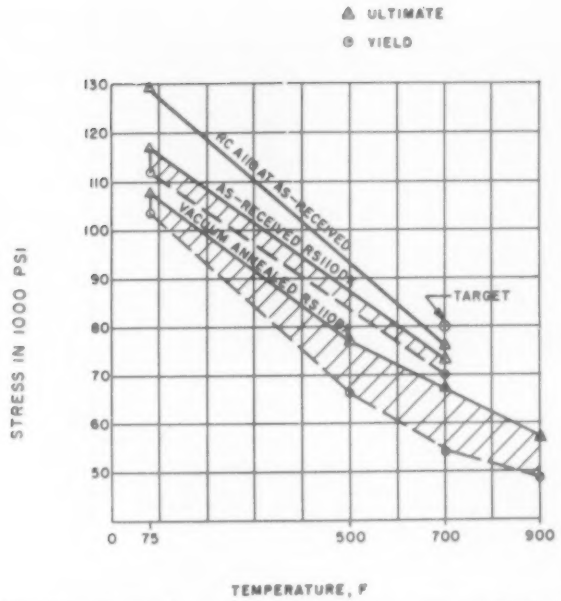


Fig. 14 Comparison of weld joint transverse mechanical properties of RS-110-BX and RC-A110-AT

demonstrated that this could not be done because the weld ductility was grossly impaired. Since the tensile failures always occur in the base metal well away from the weld or heat-affected zone it is rather difficult to say that torch transformation increases the ultimate tensile strength. However, when the stress range between the ultimate tensile stress and yield stress are evaluated it becomes apparent that a greater range always existed in specimens which were postheated in air. Thus torch transformation does two things: (1) it increases the stress range between the ultimate and yield and subsequently allows the weld to adjust itself more readily to applied strain and (2) it allows the weld to respond more readily to bending stresses. Even though both of these phenomena are directly related to weld ductility no great difference was easily detected when comparing the values reported on percent of elongation across the welds.

Metallographic investigations were made in order to determine the effect of torch postheating on the weld's grain structure. The structures associated with welds in the as-welded, postheated in the welding jig and postheated in air are shown in Fig. 15.

In as-received RS-110-BX material the grain structure of the base metal consisted of very fine, elongated beta grains within an alpha matrix. The fusion zone of welds in the as-welded condition consisted of coarse acicular alpha grains within large former beta grains at the weld center and smaller

Table 4—Mechanical Properties of Inert-Gas-Shielded Tungsten Arc Fused Square Butt Joint Welds

Specimen Code No.	*Ultimate tensile strength, psi*	*Yield strength, psi*	*% Elongation, in. 2*	*0.5*	*Porosity*	*Failure location*
Test Type: Transverse tensile weld joint strength—As-welded						
Material: RS-110-BX in a vacuum annealed condition						
Material thickness: 0.050 Heat No. R2A-647						
Test Temperature: Room						
9AE1	107,000	100,800	12.0	0.0		
2	109,600	102,600	14.0	0.0		
3	110,100	103,300	12.5	0.0	None	1/8 in. away from weld
4	111,100	105,200	11.5	0.0		
5	110,700	105,600	13.5	0.0		
Average	109,700	103,500	12.7	0.0		
Test Temperature: 500° F						
13AE6	77,600	66,900	17.5	0.0		
7	77,900	65,800	17.5	0.0		
8	78,500	66,900	20.0	0.0	Fine linear porosity	3/4 in. away from weld
9	77,800	65,200	18.0	0.0	in weld edge	
10	85,800	63,600	17.5	0.0		
Average	77,520	65,680	18.1	0.0		
Test Temperature: 700° F						
13AE1	67,400	53,600	16.5	0.0		
2	66,500	52,800	16.5	0.0		
3	67,100	52,700	16.5	0.0	Fine linear porosity	1/8 in. away from weld
4	68,800	55,300	17.0	0.0	in weld edge	
5	70,300	56,600	16.5	0.0		
Average	68,000	54,200	16.6	0.0		
Test Temperature: 900° F						
9AE6	55,900	48,200	27.5	0.0		
7	56,000	48,900	27.0	0.0		
8	56,600	48,700	26.5	0.0	None	1/8 in. away from weld
9	56,500	47,500	26.5	0.0		
10	56,500	48,000	28.0	0.0		
Average	56,300	48,300	27.0	0.0		

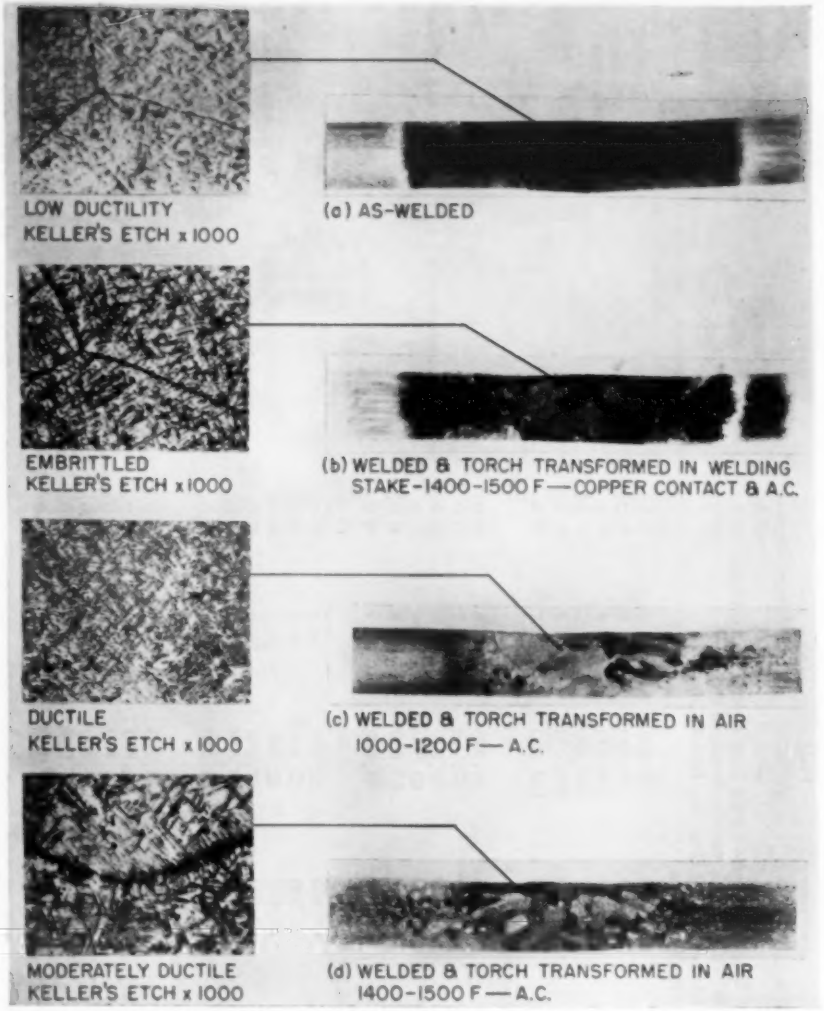

LOW DUCTILITY
KELLER'S ETCH x 1000
(a) AS-WELDED
EMBRITTLED
KELLER'S ETCH x 1000
(b) WELDED & TORCH TRANSFORMED IN WELDING STAKE-1400-1500 F—COPPER CONTACT & A.C.
DUCTILE
KELLER'S ETCH x 1000
(c) WELDED & TORCH TRANSFORMED IN AIR 1000-1200 F— A.C.
MODERATELY DUCTILE
KELLER'S ETCH x 1000
(d) WELDED & TORCH TRANSFORMED IN AIR 1400-1500 F— A.C.

Fig. 15 Grain structure of inert-gas tungsten-arc welds in as-received RS-110-BX (R2A-610)

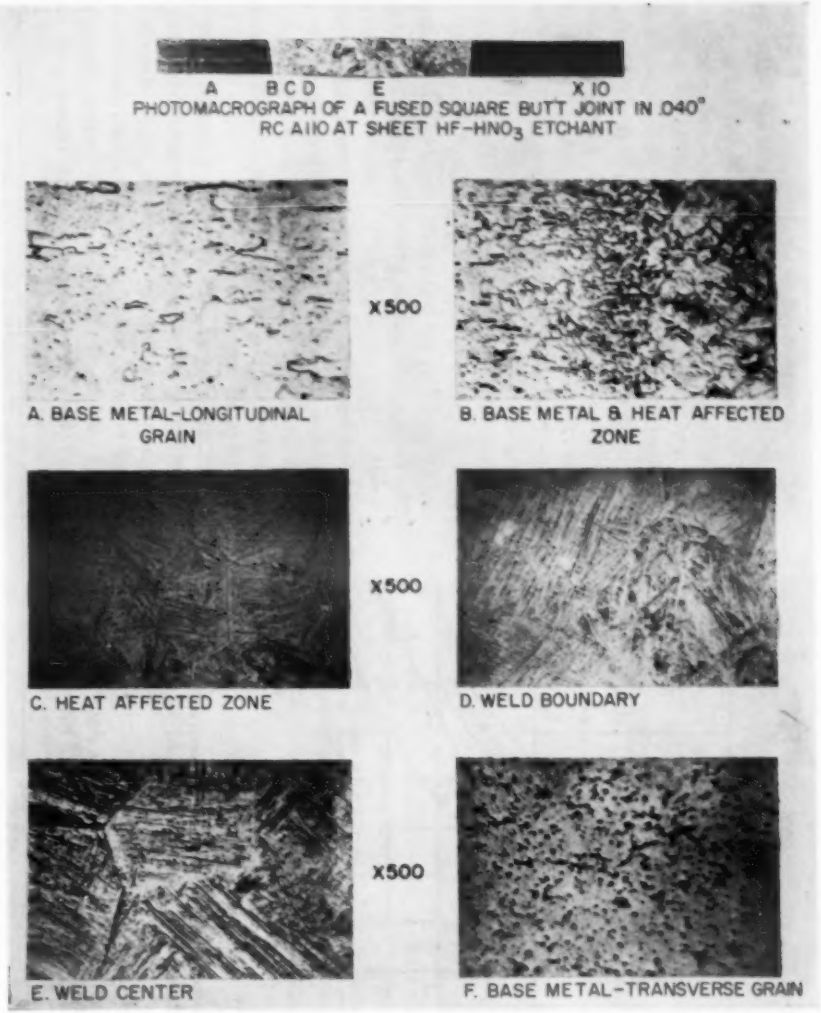

A B C D E X 10
PHOTOMACROGRAPH OF A FUSED SQUARE BUTT JOINT IN .040"
RC A110 AT SHEET HF-HNO3 ETCHANT
X500
A. BASE METAL-LONGITUDINAL GRAIN
B. BASE METAL & HEAT AFFECTED ZONE
X500
C. HEAT AFFECTED ZONE
D. WELD BOUNDARY
X500
E. WELD CENTER
F. BASE METAL-TRANSVERSE GRAIN

Fig. 16 Traverse grain structure of inert-gas tungsten-arc welds in as-received RC-A110-AT ($4^1/_2$ Al, $2^2/_3$ Sn) titanium alloy sheet

acicular discrete alpha needles within medium size former beta grains at the weld boundary. This grain structure is shown in Fig. 15*a;* the dark nodular and needle-like objects are the alpha constituents and the white background is the alpha prime matrix. This structure is sometimes referred to as Widmanstätten.

The weld's cast structure is quite strong. It has an average ultimate tensile strength of 160,000 psi, 0.2% offset yield strength of 144,000 psi and elongation of 2.7% in 2 in.

Welds which were postheated in the longitudinal hold-down stake have a grain structure similar to the as-welded grain structure. Figure 15*b* shows the grain structure of a weld which was postheated at a recorded temperature of 1500° F. The weld center consisted of coarse acicular alpha needles within large former beta grains. The only apparent difference between the weld structure of the latter (Fig. 15*b*) and the former (Fig. 15*a*) is that the latter has a more dense acicular alpha prime formation caused by double heating and rapid air cooling. Bend and tensile test results showed that this grain structure was more brittle than the as-welded type of grain structure.

Welds which were postheated in air were found to have a grain structure which is somewhat different than the as-welded grain structure. Figure 15*d* shows the grain structure of a weld which was locally postheated at a recorded temperature of 1500° F and allowed to air cool. The weld center consists of extremely coarse discrete acicular alpha needles within large former beta grains. The sharpness of the weld boundary disappeared due to recrystallization of the weld and heat-affected zones. Local torch heating at temperatures between the lower beta transus (900° F) and the upper beta transus (1500° F) causes resolution of the alpha prime and then upon slow air cooling equiaxed alpha is rejected at the grain boundaries and the former discrete alpha needles become larger.

The grain structure as shown in Fig. 15*c* and 15*d* was found not to be as strong as the as-welded cast structure but to more closely approximate the base metal's as-received mechanical properties. The postheated in air weld metal has an average ultimate strength of 128,000 psi, 0.2% offset yield strength of 118,000 psi and elongation of 3.4% in 2 in.

The grain structure of welds in RC-A110-AT all-alpha titanium alloy sheet is shown in Fig. 16. Both the base metal and weld have a coarser structure than the RS-110-BX alpha-beta alloy.

The weld macrograph of Fig. 16 and the micrograph, Fig. 16*a*, shows the base metal grain structure in the longitudinal direction (sectioned parallel to the rolling direction). The longitudinal grain structure has a different appearance than the transverse grain structure. In either grain direction the as-received base metal structure consists of moderately large equiaxed hexagonal alpha grains. However, the alpha grain boundaries are more pronounced in the longitudinal direction; compare Fig. 16*a* with Fig. 16*f*. Another difference is the contrast between the carbide distribution; in the longitudinal direction the carbides appear as stringers whereas in the transverse direction the carbides appear more nodular.

The heat-affected zone grain structure consists of short acicular alpha needles within large former beta grains. The weld center grain structure has coarse and extremely long alpha needles within very large former beta grains. This cast structure is stronger than the base metal and is not very ductile. It has an average ultimate shear strength of 112,000 psi whereas the base metal has 92,000 psi.

Circular Patch Weld Restraint Tests

Scope

The ability of the RS-110-BX and RC-A110-AT alloys to respond to the inert-arc welding process was reflected by the previous mechanical tests. These tests showed that the weld joint was stronger and less ductile than the base metal and also showed that the weld's grain structure was compatible enough to adjust itself to applied strain without causing premature failures in the weld or heat-affected zone.

The tensile, shear and bend tests were not considered versatile enough to reflect the weld's ability to withstand high weld shrinkage stresses or slow sustained strain aging stresses. Another type of mechanical test was needed to determine the effect of concentrated weld shrinkage and strain aging stresses. The circular patch weld restraint type of test was selected for this purpose.

Procedure

Preparation of the circular patch weld restraint test specimens consisted of welding 2- and 4-in. diam disks in the center of 6- and 8-in., respectively, square sheet panels. The weld joint was a square butt groove. Welding was performed manually using a conventional inert-arc water-cooled hand torch with dc–sp rectified alternating current. A simple welding fixture was used to restrain the panel's two components, see Fig. 17.

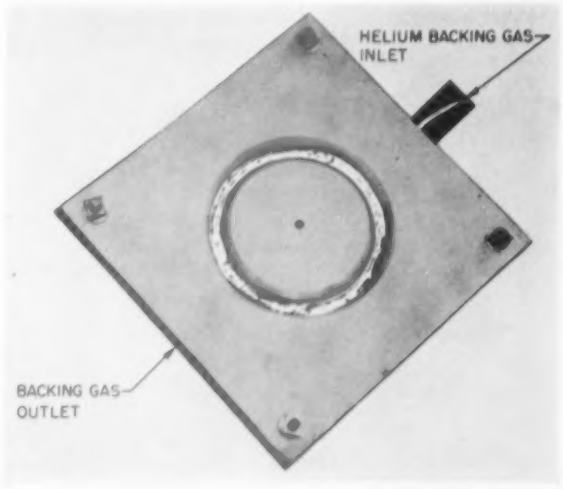


Fig. 17 Welding fixture used for manual inert-gas tungsten-arc welding of circular patch weld restraint test specimens

The welding fixture was designed to employ the same tooling principles that were used in the semiautomatic welding process; a backing bar groove of 0.040 in. deep by 0.250 in. wide and a hold-down toe space of $^5/_{16}$ in. Helium gas was used for root bead shielding and argon at the welding arc.

Four different weld conditions were examined for shrinkage effect, they were:

1. The first circular patch weld restraint specimen was welded by fusing the joint edges together.

2. The second specimen was also fuse welded and then subsequently torch postheated.

3. The third specimen was welded by adding commercially pure Ti-75A filler metal. Welds were made in one pass.

4. The fourth specimen was welded by adding base metal filler. Welds were made in one pass.

Welds were inspected for cracking with dye penetrants immediately after welding. After this initial inspection each weld was X-rayed and the type of porosity recorded for future reference in the event that porosity could possibly be correlated as a cracking effect. Pursuant to this inspection, the circular patch specimens were hung on a rack and at intervals of 10 to 15 days they were again inspected with dye penetrants for evidence of weld cracking. This procedure was used for the purpose of determining whether the residual stresses set up by normal welding shrinkage would cause cracking over any long period of time. The procedure used for determining strain aging effects consisted of placing the circular patch test specimens in a compressive test fixture and loading the specimens incrementally every 10 or 15 days until the specimen reached its estimated buckling stress (became permanently bent).

Circular Patch Weld Restraint Test Results

The alpha-beta alloy, RS-110-BX, was tested in two base metal conditions: (1) as-received and (2) vacuum annealed (hydrogen outgassed). The all-alpha alloy was tested only in the as-received condition.

Welds in as-received RS-110-BX material were found to be susceptible to transverse weld cracking after aging several months. Only the small 2-in. circular patch specimens developed cracks. The four different weld conditions had three effects on the duration of the weld's stability. The fused and torch postheated fused

Table 5—Mechanical Properties of Inert-Gas-Shielded Tungsten Arc Fused Square Butt Joint Welds

Specimen Code No.	*Ultimate tensile strength, psi*	*Yield strength, psi*	*% Elongation, in. 2*	*0.5*	*Porosity*	*Failure location*
Test Type: Transverse tensile weld joint strength Material: RC-A110-AT in a hot-rolled and annealed condition Material Thickness: 0.037 in. Test Temperature: Room						
5VW1	129,600	121,000	11.0	0.0	None	
2	129,600	121,900	12.5	0.0	Very slight	
3	129,400	123,000	12.5	0.0	Very slight	
4	129,900	125,500	9.5	0.0	Very slight	
5	129,700	123,500	10.5	0.0	None	$^3/_4$ in. away from weld
6	129,100	122,800	11.0	0.0	None	
7	129,300	123,800	9.0	0.0	None	
8	128,600	120,500	9.0	0.0	None	
Average	129,400	122,750	10.6	0.0		
Test Type: Longitudinal tensile weld joint strength Material: RC-A110-AT in a hot-rolled and annealed condition Material Thickness: 0.037 in. Test Temperature: Room						
6VW9	130,900	117,700	13.5	2.0	Medium	
10	133,100	117,300	15.0	2.0	Medium	
11	132,800	119,500	14.5	2.0	Medium	$^3/_4$ in. away from weld
12	130,600	115,900	13.5	2.0	Medium fine	
13	131,700	118,700	14.0	2.0	Medium fine	
Average	131,800	117,800	14.0	2.0		
Test Type: Transverse tensile weld joint strength Material: RC-A110-AT in a hot-rolled and annealed condition Material Thickness: 0.037 in. Test Temperature: 700° F						
6VW1	75,700	56,900	12.0	0.0	None	
2	76,300	56,500	12.5	0.0	None	
3	75,900	62,100	12.0	0.0	Incomp. penet.	
4	75,600	60,900	12.0	0.0	Incomp. penet.	
5	76,000	58,300	12.0	0.0	None	$^3/_4$ in. away from weld
6	75,200	60,000	12.0	0.0	None	
7	75,800	59,700	12.0	0.0	None	
8	75,200	61,700	12.0	0.0	None	
Average	75,700	59,500	12.0	0.0		

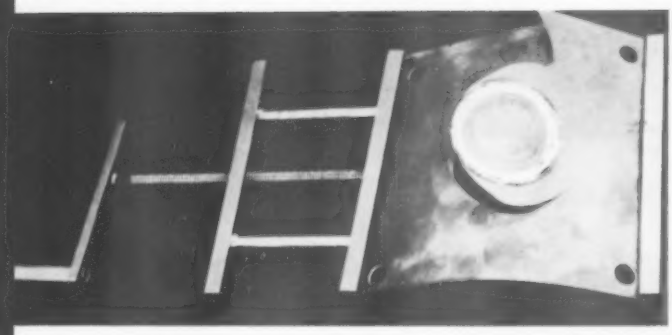


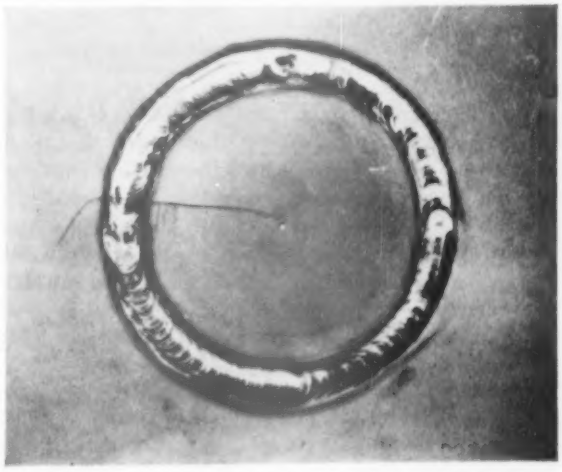
Fig. 18 *(a)* Compressive static loading test fixture used for determining strain aging and reliability characteristics of fusion welds in titanium alloys

welds did not develop cracks during a period of five months. However, these same specimens failed immediately after being compressively loaded in a static test fixture; see Fig. 18. The specimens which were welded by adding filler metal developed transverse weld cracks 4 $^1/_2$ months after welding. Figure 19 shows the type of failure.

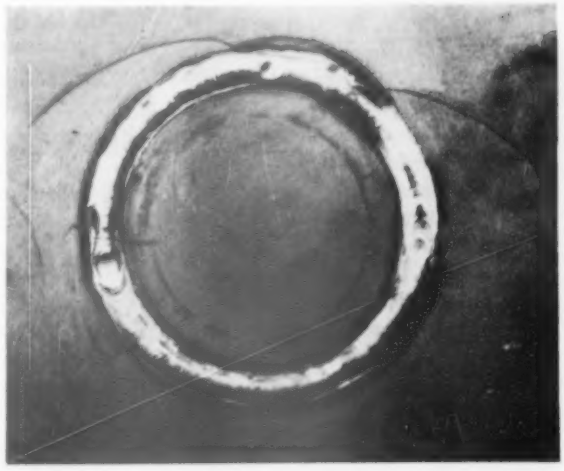
These test results indicated that the occurrence of weld cracking was not due to shrinkage stresses but more likely was caused by hydrogen embrittlement. Hydrogen analysis tests showed that the as-received material contained three hundred parts per million (0.031 H). In order to check the effect of interstitial hydrogen on welds, it was necessary to take material from the same material heat previously used and vacuum anneal it. A hydrogen analysis showed that the outgassed material contained one hundred parts per million. Circular patch weld restraint tests were made on the outgassed material in the same manner as the as-received material was tested. Five months have elapsed since these specimens were welded and no weld cracking has been detected. Since the welded outgassed RS-110-BX material held up so well it is assumed that interstitial hydrogen causes premature weld failure due to intergranular collective gas pressures set up by the formation of diatomic hydrogen. The maximum acceptable hydrogen contamination level has not been established as yet. However, it has been arbitrarily set at 130 ppm until such time that a higher or lower level is definitely established.

Welds in the as-received RC-A110-AT material held up very well. Only one of the small 2-in. circular patch specimens developed a crack. This specimen had been welded by fusing the joint edges and then locally post-heated for stress relieving purposes. The specimen was hung for 4 $^1/_2$ months without restraint and no failures were observed. It was then put into the static compression test fixture and compressed up to the critical buckling load point. After 2$^1/_2$ months under compression a crack appeared in the weld edge. Apparently torch post heating causes severe surface oxidation on RC-A110-AT which is accompanied by surface embrittlement. The failure in all probability was initiated in this embrittled weld surface because another as-

Fig. 18 *(b)* Circular patch fused weld in as-received RS-110-BX



Unalloyed filler wire added



Base metal filler strip metal added

Fig. 19 Circular patch welds in as-received RS-110-BX

Table 6—Comparison of Mechanical Properties of Welds in Three Conditions

Specimen Code No.	Weld condition	Ultimate tensile strength, psi	Yield strength, psi	% Elongation in 2 in.	Failure location
Test Type: Transverse weld joint strength Material: RS-110-BX in a reheated for 1 hr at 1230° F and air-cooled condition Material Thickness: 0.040 in. Test Temperature: Room					
6XH1	As-welded	130,300	120,700	14 5	
2	As-welded	130,400	120,000	20 0	1/2 in. away
3	As-welded	130,300	119,100	16 5	
4	As-welded	130,800	119,400	18 5	
Av.	As-welded	130,450	119,800	17 3	
3XH-12*	Welded and postheated in air (1400–1500° F)	135,000	122,500	15 3	1/2 in. away
3XH-13*	Welded and postheated in air (1100–1200° F)	136,000	...	15 3	1/2 in. away
3XH-18*	Welded and postheated in hold-down stake (1400–1500° F)	129,000	...	2 0	Weld center

* Substandard specimens, failed in bearing on first test. Retested; elongation was in 1 1/2 in.

welded specimen received the same compressive test and it never has failed.

Conclusions

The preliminary weldability studies made on RS-110-BX and RC-A110-AT sheet revealed that both alloys were quite weldable by either the automatic or manual inert-gas-shielded nonconsumable electrode processes. The success with which these alloys were welded is attributed to the precautions which were taken to eliminate atmospheric contamination of the weld's heat-affected zones and also minimize distortion and weld shrinkage during welding by suitable restraining fixtures.

The weldability of RS-110-BX sheet material fluctuated considerably because of different base metal conditions. In mechanical tensile tests all failures occurred away from the weld and heat-affected zone if the base material was in either a hot-rolled and annealed condition or a vacuum annealed condition, (see Figs. 12 & 13). However, by comparing the bend radius of the unwelded base metal with the bend radius of welded base metal it was ascertained that RS-110-BX had better weldability in the vacuum annealed condition. Bend tests also showed that welds could be rendered more ductile by a transformation heat treatment.

The minimum 180-deg face bend radius of welds in as-received sheet was found to be $8.5t$ in 0.047-in. sheet. Local torch transformation heating after welding improved the bend radius to $3t$. Since the minimum bend radius of the parent metal was $3t$, it was ascertained that the bendability efficiency was 35% for welds in 0.047-in. sheet (heat R2A-610). Upon torch transforming the welds, the bendability efficiency was improved to 100%.

The minimum 180-deg face bend radius of welds in vacuum annealed sheet was found to be $4t$ (as-welded condition). The bend radius of the base metal was $3t$; the same as as-received material. Local torch transforming of welds in vacuum annealed material improved the bend radius to $3t$, hence, giving a bendability efficiency of 100%. Hence, it was ascertained that the RS-110-BX has a fair weldability rating in the hot-rolled and annealed condition and a very good rating in the vacuum annealed condition.

This was again proved to be true when the results of the circular patch weld restraint tests were compared.

Circular patch welds in as-received RS-110-BX material did not fail within the 90-day limit test period but they did begin to fail after 130 days. On the other hand, welds in vacuum annealed material have not failed after 160 days. Although vacuum annealing causes a loss in ultimate tensile strength, it also makes the material more reliable for service applications.

The weldability of RC-A110-AT as-received sheet is considered to be on a par with the weldability of vacuum annealed RS-110-BX.

In mechanical tensile tests all failures occurred away from the weld and heat-affected zone, thus showing that 100% joint efficiencies (in square butt joints) could be obtained. The minimum 180-deg face bend radius of welds in as-received (hot-rolled and partially annealed) material was $2.8t$ in 0.023-in. sheet and $5t$ in 0.039-in. sheet. The bend radius of the base metal was $2.8t$ in both sheet thicknesses. Hence, the bendability efficiency was 100% for welds in 0.023-in. sheet and 56% in 0.039-in. sheet.

Circular patch welds in as-received RC-A110 AT did not fail within the 90-day limit test period and with the exception of one test specimen no failures have occurred since the day they were welded.

Acknowledgments

The special assistance provided by the North American Aerophysics Department is greatly appreciated. Specific acknowledgment is made to Dr. N. A. Tiner, Metallurgist and B. W. Robinson, Metallographer, who assisted materially with this investigation.

WELDED STEEL CONSTRUCTION

BY CHARLES I. ORR

Members of the AMERICAN WELDING SOCIETY are, in general, concerned with the development and application of welding techniques and processes for a great number of products and for many types of material. Engineers and architects are primarily interested in the application of these welding techniques and processes to the joining of structural members. A combination of these interests and of this knowledge is required for the successful completion of a welded structure. The members of the AMERICAN WELDING SOCIETY can render a substantial service to the engineers and architects by making available to them the necessary technical information with respect to techniques and processes of welding.

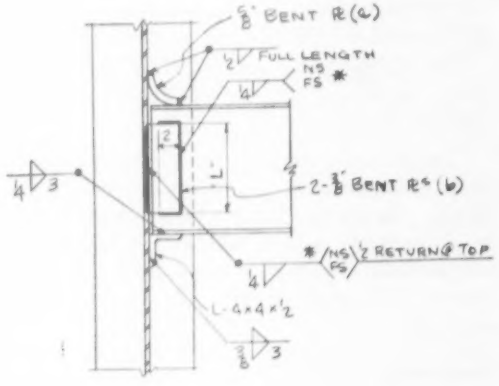
Basic Considerations

The joining of structural members by welding is a simple process compared to the processes required to make weldments with complex joint arrangement in various types of materials, including ferrous alloys and nonferrous materials. In structural welding we are concerned primarily with short welds, simple joint arrangement and mild carbon steel material. Our problems, therefore, in the making of a satisfactory welded joint between structural members, are relatively few. The use of welding provides us with just another method of connecting two or more pieces of steel to each other. This process does not require any basic change in the fundamental science of structural analysis. It is true that it is often much easier to provide rigidity in welded joints than in riveted or bolted joints. Actually one of the greatest inherent advantages of welded joints is their natural rigidity. When two or more members are fused together by welding, they become in fact one integral member.

The use of welding as a means of connecting the various parts of a steel structure has been the subject of considerable discussion and even controversy. Some individuals promote the use of welded connections with great enthusiasm. Others resist such use with equally great stubbornness. The third, and by far the largest group of design engineers, approaches this problem in an open minded, engineering analytical manner as they would any other engineering problem, with a desire to use welded joints where they are applicable and advantageous, and to discourage their use where other types of connectors can be more advantageously employed. It is quite possible that welding processes are further advanced at this time than is general design knowledge.

Design and Drawing Requirements

Design is the most important of all component parts going into a welded structure today. There is a sub-



SCHEDULE - SHEAR CONN. TO COL. WEB		
LENGTH "L"	USE FOR BEAMS AS FOLLOWS:	
	SIZE	SPAN
4"	8" DEPTH	ALL SPANS
5"	10" "	OVER 13'-0
7"	10" "	UNDER 13'-0
7"	12" "	OVER 13'-0
8"	12" "	UNDER 13'-0
8"	*14" "	OVER 9'-0
8"	15" "	OVER 15'-0
8"	16" "	OVER 18'-0
10"	16WF50	22'-0
11"	16" DEPTH	UNDER 18'-0
11"	18"	OVER 23'-0
12"	18"	UNDER 23'-0
12"	20I65.4	OVER 16'-0
13"	21WF68	25'-0 @ GROUND FLOOR
13"	21WF62	17'-1 @ 10TH FLOOR
14"	24WF76	OVER 21'-0 @ GROUND FL.

* FOR 14WF43 & 14WF48 USE 5/16" WELD ON PLS "b"

Fig. 1 Beam connection to column web

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Presented at the Jan. 20, 1955, meeting of the Los Angeles Section, AMERICAN WELDING SOCIETY.

stantial difference between drawings for a riveted or bolted job and for a welded job. The most outstanding difference is the extent of detail required. Due to the lack of standardization for welded joints, the drawings for a welded structure must show more complete information to assure the execution of the work in a manner visualized by the structural engineer. Designers and detailers of welded structures should become familiar with the AMERICAN WELDING SOCIETY Standard Symbols so that their use will convey the exact information intended. A short time ago the Committee on Welding Practice of the Structural Engineers Association of Southern California prepared a report which recommended that specific details be provided for each connection, showing the size of all detail material and of welds. This can often be simplified by the use of job standard details together with accompanying schedules (Fig. 1).

This committee also developed a series of "do's" and "don'ts" for guidance in the preparation of design drawings. Some of these are as follows:

"Do specify the minimum amount of weld that will satisfy governing conditions. Do not over weld. Do not use all around symbol promiscuously."

"Do keep welded joints simple in design. Do design for downhand welding where feasible" (Fig. 2).

"Do design joints especially for welding. Do not design joints for riveting and then note them to be welded" (Fig. 3).

"Do take into consideration standard mill tolerances of rolled shapes and what effect they may have on the detail. Do not use details which depend on such shapes being perfectly square and to exact dimension. Do not use a direct butt weld and a splice plate on the same joint for the same purpose. Do use one or the other, not both."

Economy

In the interests of economy, welded details should be kept as simple as possible. The designer of welded structures will do well to disregard practices and details previously used for riveted joints. Gusset plates, splice plates and similar fittings are usually not necessary in welded construction. Parts should be designed and detailed so as to provide good accessibility for fitting and for performing the welding with the electrode in the proper position, and so that the operator can see his work clearly. The relative size of welds is also a major economic consideration. A $^5/_{16}$-in. fillet weld can be made with one pass. A $^3/_8$-in. fillet weld requires two passes or almost twice as much labor and 40% more weld metal, but is only 20% stronger than the $^5/_{16}$-in. fillet weld.

The welded base plate provides a typical simple example of welded construction and is all too often subjected to the common sin of overwelding. Base plates are welded to column shafts to resist calculated moment, shear or uplift—or a combination of these factors—or just to stick the thing in position so that it will not be misplaced. The weld required for any of these, except perhaps the last one, can be calculated. However, it is much easier to call for a weld of generous size and add a little circle to the symbol which says "weld all around." The base plate for 8WF31 may be held securely welded in place by a minimum of four 2-in. welds (a total of 8-in.) whereas the total dimension all "around" is 48-in. There is no more reason to double the required size of the weld than there is to double the size of the column shaft or of the base plate (Fig. 4).

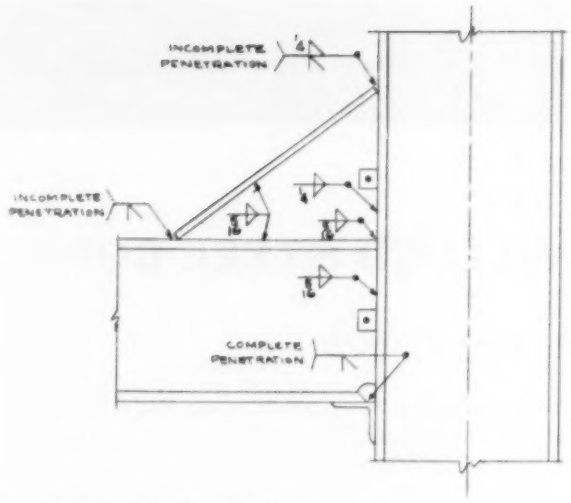


Fig. 2 Simplicity of joint design

The position of the weld is also important with relation to cost. In its normal progress through the shop, an H section is placed on stands with its web vertical. With the H section in this position it is simple to attach our base plate by making a downhand weld on the outside of the top flange and on the inside of the bottom flange. While the section is still in this position a vertical weld may be made on one or both sides of the web. If welding on opposite sides of the flanges is required either the column section must be turned over or overhead welding must be used. Both operations cost money.

Specification Requirements

Specifications can usually be quite simple. The "Standard Code for Arc and Gas Welding in Building Construction" of the AMERICAN WELDING SOCIETY is almost universally accepted and can be incorporated in the specification by reference. This code is now in the process of revision and we hope that it will be brought up to date to include submerged arc welding, revised material specifications and other data in the not too distant future. The AMERICAN WELDING SOCIETY's "Specifications for Welded Highway and Railroad Bridges" may also be incorporated by reference when applicable. Certain sections of this specification may apply to structures other than bridges when such structures are subject to dynamic or vibratory loading.

The job specifications should also list the qualifications of or additions to the AWS specifications prev-

iously mentioned. For instance, either the specifications or the drawings should definitely state whether butt welds are "incomplete penetration" or "complete penetration" and should specify definite inspection requirements. Specifications should not impose unnecessary or impractical restrictions relative to materials, procedures or inspections.

Material

The material specification has been a subject of considerable discussion for several years. By far the greater percentage of steel used in structures for many years has been produced under ASTM Specification A-7. Practically all building codes require that structural steel conform to ASTM A-7. This specification does not provide a maximum limit for carbon content. Since steel becomes progressively more difficult to weld as the carbon content increases, this lack of control of carbon content in A-7 steel has been a matter of concern to engineers and welding technicians. Federal Specification QQ-S-741 Type II steel provides for a structural steel with definite maximum limitations of carbon content and is for use in welded construction. This specification was revised and simplified in 1952 and reissued as tentative specification QQ-S-00741. In 1954, ASTM issued Specification A373–54T which is essentially the same as QQ-S-00741. Therefore, we now have a standard specification for steel designed especially for welded structures.

Although these later specifications offer technical advantages, they do, at times, create problems with respect to availability of steel. Because of the great variety of shapes and sizes of members required for steel structures, it is difficult for the fabricator or warehouse to maintain adequate inventories under one specification. It is therefore reasonable to assume that stocks will, in general, be limited to A-7 steel and that steel under specification QQ-S-00741 and A373–54T must be mill ordered. It is recommended that the use of these specifications be limited to steel that can be mill ordered—that is, with respect to the time element and minimum quantities. The carbon content of A-7 steel in members less than one inch thick is normally within the maximum limits required by the later specification. It is also quite possible to make satisfactory welded joints with steel of higher carbon content by the use of proper procedure. It would therefore appear desirable to continue to use A-7 steel for "out-of-stock" jobs. The minimum tensile strength of 60,000 psi specified in A-7 is reduced to 58,000 psi in QQ-S-00741 and in A373–54T and the minimum yield point is reduced from 33,000 psi to 32,000 psi.

It is assumed that building departments will approve this slight reduction in ultimate strength without requiring a reduction in working stresses.

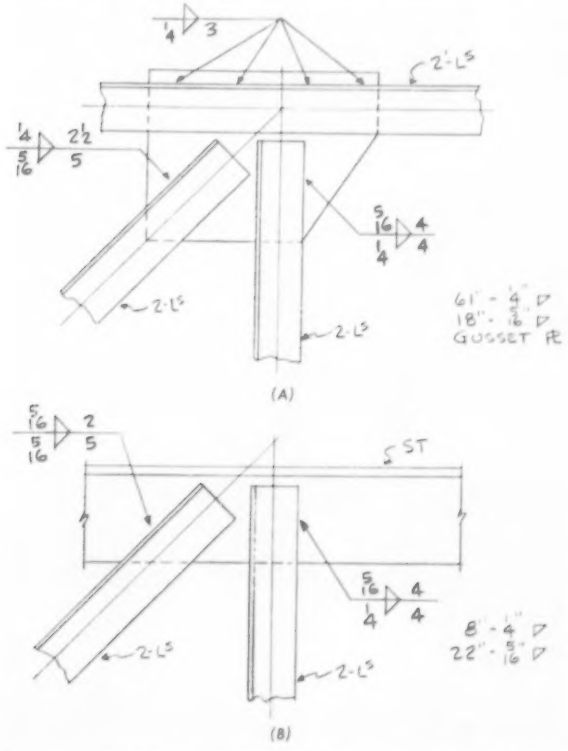


Fig. 3 (A) Joint designed for riveting. (B) Joint designed for welding

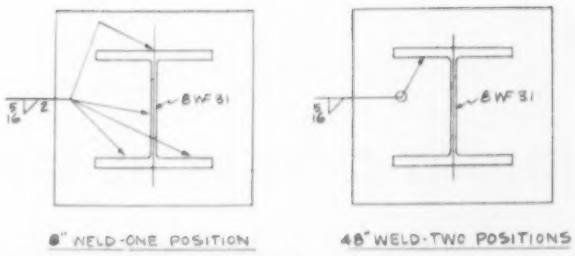


Fig. 4 Column base—8WF31

Reliability of Connections

The design engineer must have confidence in the method of connection he specifies. Repeated tests and the performance of structures has shown that the normal welded joint is stronger than the base material. It is reasonable to assume that good welding will be obtained when sound regulations such as contained in the American Welding Society Building Code are followed by a competent organization. The allowable working stresses, specified by code, include an ample factor of safety so there is no need to use excessive quantities of weld.

Recommendations

The author recommends that particular attention be given to the simplification of welded details, to the elimination of overwelding and to the inclusion of adequate design and detail data on the working drawings. The registered engineers employed by fabricators have an opportunity to observe a wide variety of designs as well as the process of fabrication. Many of them are also engaged in extensive research. The author therefore, likes further to recommend the closest cooperation between engineer and fabricator in the interest of economical and efficient welded structures.

SHORT CUTS IN SCRAP CUTTING

Crucible Steel and R. M. Chambers achieve savings with different techniques

BY W. E. McLAUGHLIN AND C. F. STEINBERG

Two outstanding—and different—examples of highly efficient scrap-cutting operations are represented by techniques used at Crucible Steel Co., Midland, Pa., and R. M. Chambers Co., Pittsburgh, Pa.

Both have the same objective—maximum economy of operation in reducing scrap buttons to charging-box size—*but* each has a different work area problem. Both use the same oxy-acetylene cutting equipment *but* each uses the equipment in a way that best meets the job requirements. Through ingenuity both have solved tough problems and come up with savings in time and money over previous methods. Here's how they did it.

At Crucible, Scrap Comes to the Torch

With a compact work area, Crucible Steel concentrates scrap-cutting operations in a large, specially built pit, spanned by a motor-driven bridge which moves the entire length of the pit. A carriage machine and motorized arm with a heavy-duty torch and heavy-duty gas controls are mounted on the bridge. Dump cars pile buttons into the pit, then bridge and torch go to work, with an easy sychronization of motion that permits a high degree of positioning for cutting. The cutting unit supplies transverse motion to the torch, and the motorized torch arm provides its own longitudinal cutting motion in addition to the movement of the bridge. Oxygen and acetylene are piped to the working point from central sources of supply.

With only one torch and one operator, Crucible's centralized cutting operation reduces the entire output of buttons to charging-box size.

At Chambers, the Torch Goes to the Scrap

A large work area, with literally mountains of scrap, posed a problem at Chambers. Here, obviously, Mohammed had to go to the mountain! The Mohammed in the case—the oxy-acetylene cutting equipment—had to be mobilized. Chambers mounted it on a special

W. E. McLaughlin, Technical Sales Representative, and C. F. Steinberg, Steel Mill Representative, Air Reduction Sales Co., Pittsburgh District.

Fig. 1 Flame eats into scrap. Huge buttons yield to torch, are cut into charging box size

Fig. 2 Huge scrap button about to be cut—oxy-acetylene cutting equipment goes to work

Fig. 3 Cutting unit gives crosswise motion to motorized torch arm which adds its own lengthwise motion to bridge as it cuts scrap at Crucible

Fig. 5 R. M. Chambers' cranes at work on scrap mountain; huge steel ball knocks off loose slag and dirt and breaks down scrap

Fig. 4 Scrap comes to the torch at Crucible. Cutting equipment mounted on motor-driven bridge which spans large scrap assembly pit

Fig. 6 Torch goes to the scrap at Chambers. Cutting equipment, including motorized torch arm, mounted on 35-ft skid, is moved into position

skid, 35 ft long, which could be moved from place to place by a bulldozer. The operation is smooth and efficient. Shovels and cranes pick up the scrap unloaded by dump cars; a huge steel ball knocks loose slag and dirt off the buttons and breaks down the scrap which is then assembled for cutting. A bulldozer pulls the skid into place and the torch is ready for cutting. A bulk delivery oxygen system in trailers follows the skid from point to point, maintaining a distance of 100 to 150 ft. Acetylene is supplied from manifolded cylinders mounted on skids for mobility. Rubber hose provides flexibility of movement.

Centralization is the answer at Crucible; *mobility* at Chambers. The high adaptability and versatility of the oxygen-cutting process is the answer for both companies.

ELECTRICAL CONSTRUCTION SIMPLIFIED BY STUD WELDING

BY RICHARD SAWYER

Six new warehouses, each measuring 200 x 1000 ft, recently completed at the U. S. Army's Memphis (Tenn.) General Depot, called for a major fastening operation in hanging 140,000 ft of electric conduit, 4020 outlet and switch boxes and 3726 lighting fixtures from structural steel ceiling and wall members.

The great size of the job led the contractor Shelby Electric Co., Memphis, Tenn., to experiment in order to find the one fastening method most economical from the standpoints of time, skill and materials. There were three available methods: (1) steel supporting beams could be drilled or punched, and conduit hangers and outlet boxes then bolted through the holes; (2) powder-actuated tools could drive bolts through the metal; or (3) studs could be end welded to the steel with stud-welding equipment, leaving threaded ends available for hanging conduit and boxes. Since the latter two methods required a crew of only three men to lay out and set 400 studs a day, while drilling or punching required a crew of nine men for the same number of holes, the through-bolting method was eliminated. Further, the contractor found that stud-welding material costs would be less than one-third of powder-actuated stud costs. Therefore, stud welding was the method chosen and used throughout the six warehouses. Almost 33,000 studs were installed, using two stud-welding guns and control units with one portable battery unit.

A brief explanation of the stud-welding principle will help clarify the installation. The stud welder places the threaded end of the stud in the chuck of an arc-welding gun. Setting the exposed precision-centered solid flux of the stud at the point of welding, he simply pulls the gun "trigger," and the stud is welded automatically. Duration of the welding arc is precisely regulated by the integral stud-welding control unit. On overhead construction work without a production jig, one man may weld studs up to six a minute.

Total cost to the contractor for studs complete with arc shields was $1150.35, about $250 more than bolts of the same sizes. Despite the higher cost of studs, the two-thirds saving in man-hours enabled the con-

Richard Sawyer is District Engineer, Stud Welding Division, K S M Products, Inc., Merchantville, N. J.

Fig. 1 Conduit was secured to upright and ceiling girders with fully threaded end-welded studs. Insert shows typical use of these studs designed to allow for close nut run down. Light fixture boxes were secured in the same manner as switch box in other photograph and illustration

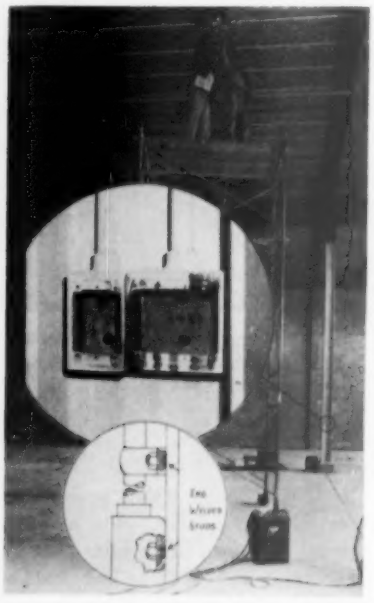


Fig. 2 The two men at top center using measuring stick and template, accurately positioned the studs to receive the clamps and outlet boxes

tractor to realize an over-all cash saving of $8500 by the use of stud welding over alternate fastening methods. Time savings alone amounted to $110.40 for each of 77 working days on the six buildings.

Additional benefits of the stud-welding method became apparent as the construction proceeded. Since the men had to work from only one side of the structural members, and did not have to hold bolt heads with one hand while holding outlet boxes and running nuts with the other, the job of assembling the electrical equipment on hangers was considerably speeded. While this saving could not be measured or added to the advantages of fastening by welded studs, it proved especially important in speeding the conduit and fixture hanging after stud installation. Another advantage to the stud-welding procedure was that since the studs almost "welded themselves" the need for supervision was greatly reduced.

ALL-WELDED SCAFFOLD SPEEDS RECOVERY OF CRASH VICTIM

An unusual welding project was recently completed by Hahn & Clay of Houston, Tex., all because of an automobile accident occurring early in 1955 in Louisiana in which Virgil Osborne, District Manager of the Southwest Area for the Farrel-Birmingham Co., was seriously injured.

The accident injured the patient's back to the extent of shortening his height of 5 ft 11 in. to 5 ft 9 in. The patient's personal physician prescribed traction devices at the hospital, but weeks later the patient was restless and impatient to be "back on the job." Faced with more weeks of confinement, the patient asked his doctor about the possibility of speeding up his recovery.

The doctor explained that recovery might be accelerated if there were some means of exerting sufficient weight on the neck and backbone. It would have to be evenly distributed and steadily applied to stretch the patient's back to its normal shape, thereby removing the "kinks" and wrinkles resulting from the accident.

This led to the design of a device which would elevate gently and vertically a 200-lb, 6-ft human body to swing clear of the floor (see accompanying illustration). Basically of a tripod design, the "Neck Stretcher" was made of aluminum bars and tubes to provide a unit that could be easily transported. It was constructed for ease of handling, assembling and disassembling. Inert-gas tungsten-arc process was used to make all necessary welds.

To simplify the procedure for elevating the injured patient, a set of pulleys was designed, attached to the apex of the tripod and to a double hooked horizontal bar

(Left) Patient at ease with his full weight hanging by the neck. *(Right)* Scaffold, completely disassembled, weighs only 15 lb

spread to the exact width of the patient's head and made to fit a conventional canvas head traction device.

One week from the birth of the idea, the patient was "hanging" vertically for the necessary traction. After three days, he was able to sustain hanging for intervals of several minutes, which freed his back from the overlapping of bones, etc. He left the hospital—on the road to recovery.

Fig. 1 Ten steel grain storage bins nearing completion in Casa Grande, Ariz. The welding rig seen on two of the bins for making field joints eliminated scaffolding, thereby speeding welding operation

STEEL BINS FOR GRAIN STORAGE

BY WILLIAM F. FISCHER

Ten grain storage bins (Fig. 1), each 30 ft, 6 in. in diameter, 60 ft high, and having a capacity of 1000 tons, were completed in five months by the Consolidated Western Steel Co., Phoenix, Ariz. They were erected in Casa Grande, Ariz., at a total cost of $200,000.

The bins are of all-welded steel construction having a cone top and bottom. Steel plate of $^{5}/_{16}$-in. size was used for the first two courses of the sides while the re-

William F. Fischer is District Engineer, Lincoln Electric Co., Phoenix, Ariz.

Fig. 2 Cone tops were field assembled by bolting, then welded and hoisted into position

Fig. 3 Truck dumping rig is seen in background. Power on the site permitted use of motor generator sets as well as gas engine-driven welders

mainder was constructed of $^1/_4$-in. and $^3/_{16}$-in. plate. The plates were tacked leaving a $^1/_8$-in. opening and were butt welded from both sides using E-6010 electrodes. The bottom cone was made of $^5/_{16}$-in. plate and the top, $^3/_{16}$-in. plate. The top was a field assembly job; the segments being bolted together and then lap welded (see Fig. 2). An iron-powder type electrode, was used for downhand joints on the top segments. Fifteen to twenty men were kept on the job until it was finished.

Since some power was available, eight 300-amp motor generator sets were used along with four 200-amp and four 300-amp. engine-driven welders. A special rig was used to hold the men doing the welding on the side of the bin. It consisted of a steel frame which had two wheels to ride on the course already welded, and two grooved wheels at the top of the rig that rode on the top edge of the course which has been tacked on and was to be welded.

The bottom cone holds the grain above ground, thus eliminating construction of an expensive underground conveyor system. The dumping rig seen in Fig. 3 is used for dumping grain out of the trucks and eliminates the need for farmers owning expensive dump truck equipment.

WELDED ALUMINUM TRAILER TRUCKS BEAT CORROSION PROBLEM

A fleet of drop bottom trailer trucks with inert-gas metal-arc welded hoppers made entirely of aluminum have been built by the Euclid Road Machinery Co., Cleveland, Ohio. Each truck is designed to haul 44 tons of lignite to fire the steam turbo-generators at Aluminum Company of America's Rockdale aluminum plant in Texas. The aluminum trucks are 8000 lb lighter than trailers of similar design made of steel and are highly resistant to the acid corrosiveness of the lignite.

Practically, the only mechanical fasteners used in the trailer bodies are the bolts which hold the draw bar to the hopper. The remainder of the hopper body is of welded construction. As the weld area is shielded with argon during the inert-arc welding operation, the need for flux and the possibility of flux entrapment were eliminated. No costly postwelding chipping or grinding was necessary on these clean, sound inert-gas metal-arc welds.

From a story by Linde Air Products Co., New York, N. Y.

Fig. 1 Inert-gas metal-arc welding of aluminum torque control members

Fig. 2 The entire hopper of this 44-ton capacity dump truck is made entirely of welded aluminum plate and extrusions

IRON-POWDER ELECTRODE SAVES THROUGH BEAD SHAPE AND APPEARANCE

BY G. N. BULL

By replacing a conventional E-6013 electrode with an iron-powder type electrode, Guaranteed Welding Service Co., Clifton, N. J., has reduced the cost of a number of rubber-lined, welded steel tanks (Fig. 1) by approximately 12%. This reduction was made possible by the high deposition rate of the iron-powder electrodes and their easy cleaning properties.

Construction of the tanks consists of cutting the $^1/_4$-in. SAE 1020 steel plates to size and welding the sides and bottom together with fillet welds. The dividers and end plates are inserted and are also fillet welded. Open corner welds are used in joining the edge flanges to the tank sides. Circular sections (Fig. 2) are added as saddles for bearings used on weighing equipment.

G. N. Bull is District Engineer, Lincoln Electric Co., New York, N. Y.

Fig. 1 Tank on left was welded with an E-6013 electrode; tank on right, with an iron-powder electrode. Bead appearance and shape is important for subsequent rubber lining. Note difference in bead size and shape on corner welds

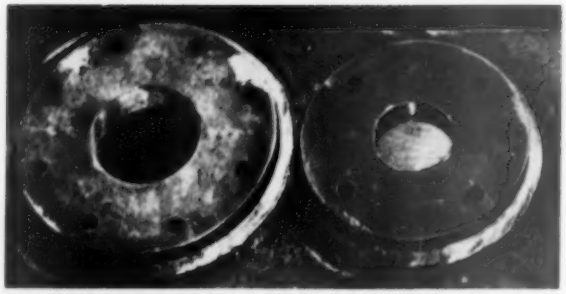


Fig. 2 Close-up of the bearing saddles shows the smooth appearance of the welds

Part of the savings gained from changing to the iron powder electrode from an E-6013 electrode was made possible by increased welding speed. However, a larger part of the savings came from the excellent cleaning properties of the electrode. Since all the welds must be ground flush for insertion of a rubber liner, slag removal, bead shape and smoothness, and amount of spatter are of primary importance. Under certain joint conditions, iron-powder electrode slag peels by itself upon cooling (Fig. 3). Beads are clean, flat and smooth, equal to automatic welds in appearance. There is little spatter with this type of rod.

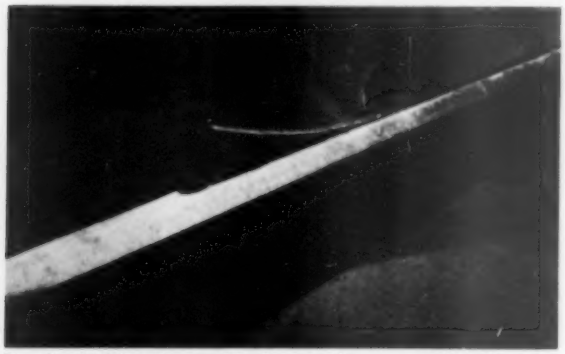


Fig. 3 In this edge weld, slag peels upon cooling, leaving the smooth, flat bead

Society News

Papers Committee Completes Technical Program for Fall Meeting

A tentative program of 21 technical sessions has been planned by the Technical Papers Committee for the National Fall Meeting to be held in Philadelphia, October 17–21, 1955. The number and variety of subjects to be covered promises to make it one of the best balanced programs in recent years. Also, papers will be presented by authors from England and Japan, giving the meetings an international flavor.

Some of the highlights of the program are:

- Three papers on carbon dioxide shielded-metal arc welding.
- A session on welding stainless steels, including an important paper on the properties of Modified Type 347 weld deposits.
- Two papers on welding titanium, including one describing how to produce ductile resistance welds in commercially pure titanium.
- Two sessions on practical applications of welding. Subjects covered are welded machinery, new approaches to welding with continuous-fed electrodes, submerged arc welding and pressure welding continuous rail.
- Six papers on piping and pressure vessels, including a description of an unusual application of inert-arc welding to heat exchanger finned tubes.
- Three sessions on weldability and research. One of these papers on effect of preheating on stress-corrosion cracking should be of particular interest to heavy weldment fabricators.
- A session on welding in the shipbuilding field, including an important paper on welding operations on offshore drilling barges.
- Papers on metal powder electrodes and their applications.
- A session on brazing, including a description of how mechanized brazing is applied to fan components.

New Booklet Describes AWS Activities

A new booklet explaining the purposes and activities of the AMERICAN WELDING SOCIETY and describing the benefits of membership has just been completed.

The 12-page, two-color brochure, prepared by the National Publicity Committee, will be used to inform prospective members about the SOCIETY. Major emphasis will be directed toward placing it in the hands of possible sustaining and supporting members.

In the near future the booklet will also be mailed to every AWS member to tell them what their SOCIETY is doing. Each member will be asked to pass on his copy to a prospective member as part of a member-get-a-member campaign.

The booklet is attractively designed in gray and white and contains charts showing the growth of AWS since its founding in 1919. Photographs of typical AWS activities are also included. Accompanying each brochure is a newly designed membership application form.

TAC TALKS

Brazing and Soldering

by A. N. Kugler

Brazing and soldering have been the subjects of many technical papers, but have never been covered in an exhaustive over-all publication such as the "Recommended Practices" issued by the various AWS technical committees. Therefore, one of the first tasks which the AWS Committee on Brazing and Soldering undertook was the preparation of manuals on brazing and soldering.

Because the writing of a brazing manual was an entirely new venture, much time was devoted to the development of the necessary data and the organization of these data into a readily usable form. In a period extending over four years, the Committee met frequently and, at times, on three consecutive days to review the manuscript. Every item was carefully reviewed and checked by practically every committee member.

The result of this work is the *AWS Brazing Manual** which has just became available. To the best of our knowledge, this is the first time brazing has been treated completely in one publication. Since the membership of the Committee includes outstanding experts in the field of brazing, AWS members are assured of an authoritative book on this timely subject.

The other phase of the original problem—soldering—has been under study, in a similar manner, for an almost equal period of time. Work has progressed to the point where it is expected that the *AWS Soldering Manual*, another pioneering book in an important field, will be available soon.

A. N. Kugler is Chairman, AWS Committee on Brazing and Soldering, and Chief Welding Engineer, Air Reduction Sales Co., a Division of Air Reduction Co., Inc.

* The *AWS Brazing Manual*, published by Reinhold Publishing Co., is a hard-covered book of 240 pages. It is priced at $4.75; AWS members may purchase it at a 20% discount.

For a Complete, Illustrated Report on the

1955 AWS National Spring Meeting

Be Sure to Read August Issue of THE WELDING JOURNAL

THINGS YOU SHOULD KNOW

When our SOCIETY was founded in 1919, those who organized its management structure must certainly have been endowed with keen foresight. They created an organizational pattern which served the SOCIETY and the industry well indeed for many years. It is only now, more than 35 years later, that we are forced to consider changes in structure.

The AMERICAN WELDING SOCIETY is growing in numbers—fast. Its membership has more than doubled during the past 15 years. At the same time, its activities and interests have increased tremendously. Periodically, it receives requests to perform new tasks and explore new fields of endeavor for the welfare of its membership and the welding industry, activities that are both vertical and horizontal. It is evident, then, that still greater expansion and extension must be the order if the AWS is to perform the function for which it was created and attain the objectives established as its goal—the SOCIETY must strengthen itself organization-wise so that it will be adequately geared to handle its task.

Recognizing these needs, the Board of Directors have authorized the organization of a Special Committee to Study AWS Organization Structure with power to bring forward recommendations for reorganization to the Board itself. Past-President Fred L. Plummer has been appointed Chairman of this new group and is now making the necessary arrangements for its organization.

• Effective on June 1st, Lewis Gilbert, executive editor of *Industry and Welding*, will assume the office of Chairman of the National Membership Committee. "Lew" gets about the country quite a bit, and is an ardent booster for AWS.

J. E. (Ed) Dato retires from the same office after 13 months of real promotion effort. Every Section Officer feels that he personally knows "Ed" as a result of his monthly breezy, informative and human-interest Membership Memos. Thanks a lot, "Ed," you did a swell job. Good luck, "Lew," for your coming year.

• This has been a "humdinger" of a year, starting with January 1st. Your Secretary, from January through mid-June, has actually spent less than 30 days in the Headquarters Office. He has been in the air so much between AWS Section cities, that he has a permanent "humpback" due to eating out of his lap. Part of his tours were with President J. H. (Joe) Humberstone, who accompanied your Secretary along the Gulf Coast, through the Southwest and up the West Coast, telling, along the way, in his friendly, down-to-earth style, AWS members and industry what AWS has been doing and its plans for doing even more. Right here, both "Joes" want to thank all the Sections they visited for their wonderful hospitality and excellent turnouts. Together, we attended the International Acetylene Assn. meeting at Houston, Tex., and the Western Metals Congress at Los Angeles; both affairs were fine. The Secretary also attended our Cleveland Section Symposium, our Detroit Section Ladies Night Dinner Dance, and our Washington, D. C., Section Annual Dinner, all grand experiences.

• On April 29th, the SOCIETY's Executive Committee held a regular meeting in Pittsburgh, Pa., at the Hotel Carlton House, where they transacted a healthy volume of business. Pittsburgh incidentally, is certainly putting on a "new face"—new buildings, new bridges, new hotels and new atmosphere. The entire Executive Committee, Assistant Secretary Frank Mooney and your Secretary were guests of the Pittsburgh Section that evening at their Annual Tri-State Dinner. Wish all of our members could have seen the beautiful welded iron decorative table, with welded AWS emblem worked into the structure, which was given as the grand prize. This table was built by Joe Minnotte, our Pittsburgh Section Secretary. Mr. Minnotte has given over a quarter century of service to the welfare and affairs of his Section—orchids, and more, are certainly in order!

JOE MAGRATH

What AWS Means to All Its Members

Membership in the American Welding Society means many services and benefits for all its members. Here are a few:

- Up-To-Date Welding Information
- Idea Exchange
- Information from the Experts
- Technical Assistance
- Codes, Standards, and Specifications
- Pooled Knowledge
- Research
- Advance with Welding

Bulletin No. 22—Welded Tee Connections

The WELDING RESEARCH COUNCIL has just issued Bulletin No. 22, "Welded Tee Connections," giving strain measurements and hydrostatic tests to destruction of various methods of providing reinforcement of welded tee connections in large diameter gas transmission pipe. Bulletin consists of 24 pages. Price: $1.00 per copy. Limited edition. Copies may be ordered through the

American Welding Society
33 West 39th Street
New York 18, N. Y.

Second Annual Midwest Welding Conference

The second annual Midwest Welding Conference will be held Feb. 1 and 2, 1956, at Armour Research Foundation of Illinois Institute of Technology, Chicago.

Dates for the event, sponsored jointly by the Foundation and the Chicago section of the AMERICAN WELDING SOCIETY, were announced by Harry Schwartzbart, research metallurgist at the Foundation, who is conference chairman.

Twelve speakers who will consider various phases of welding are to be featured at the two-day conference. Three talks each will be devoted to two topics—resistance welding and design for welding.

Approximately 180 persons attended the first welding conference held last February at the Foundation.

Happy to Know We Were Wrong!

In the caption accompanying the "Old Timers" photo on page 474 of the May issue of The Welding Journal, we identified Mr. Bernard C. Tracey (No. 28) as being "deceased." We are most happy to announce at this time that, according to recent information received from our good friends at the General Electric Company, Mr. Tracey is very much alive and enjoying fine health. Please forgive us our error, Mr. Tracey, and accept our warmest wishes for many, many more years of good health and happiness!

The Editors

Section News and Events

as reported to Catherine O'Leary

RADIOGRAPH INSPECTION OF WELDS

Albuquerque, N. Mex.—The *Albuquerque* Section held its April meeting on Friday, April 15th, at 8:00 P.M. The meeting was held in the Industrial Arts Building, University of New Mexico, and an excellent program on Radiographic Inspection of Welds was presented by Stuart Ravenbyrne, radiographer, ACF Industries, Inc., Albuquerque, N. Mex.

This was a busy week for welding in Albuquerque; and since this meeting followed two distributor welding clinics, the Section was pleased to have a turnout of about 25 members and guests.

The officers of the Albuquerque Section feel that their first year of operation as a Section has been a fruitful one from the standpoint of education, association and experience; and they hope to maintain steady Section strength and activity based upon the first year's experience.

INERT ARC WELDING

Albuquerque, N. Mex.—The meeting of the *Albuquerque* Section started at approximately 8:00 P.M. on the evening of May 20th in the Industrial Arts Building of the University of New Mexico. Chairman Willis Groth announced the results of the election of officers as follows:

Chairman—O. S. Howard, Brown & Olds Plumbing Co.
1st Vice-Chairman—Charles Boettcher, Sandia Corp.
2nd Vice-Chairman—J. J. Flowers, Santa Fe Railroad
Secretary—William McClure, ACF Industries
Members-at-Large—Olav Nerhus, Sandia Corp.; W. L. Childers, W. L. Childers Welding & Machine Works

Executive Committee Members retained include:

Treasurer—B. P. Stanage, Valley Welders Supply Co.
Members-at-Large—Charles Bowen, Big 3 Welding Supply Co.; George Elkins, Albuquerque Foundry & Machine Works

Vern Havo, local representative of the Linde Air Products Co., introduced the principal speaker of the evening, R. A. Scott of the Linde Air Products Co., Denver, Colo.

Mr. Scott gave a short talk on the principles of the inert-gas-shielded consumable-electrode welding process and showed two illustrative films, "Aluminum Welding" by Alcoa, and a high-speed motion picture on arc characteristics by Linde.

Following a short question-and-answer period, a group of approximately 75 adjourned to the welding laboratory for a live demonstration by Mr. Scott of the welding of steel and aluminum. Mr. Havo also gave a short demonstration of powder cutting of aluminum, cast iron, etc. Due to the persistence of the audience, this "2-ring circus" continued until nearly 11:00 P.M. and appreciation was widely expressed.

ELECTRODES

Fort Wayne, Ind.—The April 21st meeting of the *Anthony Wayne* Section was held in the conference room of the American Steel Dredge Co. with an attendance of about 60.

Jerry Hinkel (AWS), of the Lincoln Electric Co., gave a most interesting talk on electrodes in general and also on the new iron-powder electrodes and their recent AWS Classification.

STRUCTURAL WELDING

Phoenix, Ariz.—LaMotte Grover (AWS), of the Air Reduction Co., Inc., New York, was the guest speaker at the May 26th dinner meeting of the *Arizona* Section. His subject, "New Specifications and Practices for Structural Welding," was illustrated with slides.

The newly elected officers were introduced as follows:

Chairman—William F. Fischer, Lincoln Electric Co.
1st Vice-Chairman—Larry L. Klemmer, Smith & Klemmer
2nd Vice-Chairman—William Garland, Garland Steel
Treasurer—Keith Rousseau, Consolidated Western Steel
Secretary—Robert W. Sferra, Consolidated Western Steel
Executive Committee—Paul Baum, Luke Air Force Base; John Maffeo, Maffeo & Son

PLANT TOUR

Cambridge, Mass.—An afternoon and evening plant tour was made by 138 members and guests of the *Boston* Section on May 16th through the new modern twin steel warehouses of the Brown & Wales Co. in Cambridge. This was an excellent opportunity to observe modern methods of packing, handling and cutting of steel products, as well as the most modern flame cutting and plate shearing warehouse on the East Coast.

The evening program was under the direction of the Brown & Wales Co. who showed a colored movie entitled, "Steel Spans the Chesapeake." The film was shown through the courtesy of the Bethlehem Steel Co.

ELECTION OF OFFICERS

Bridgeport, Conn.—The *Bridgeport* Section announces the election of the following officers for the 1955–56 season:

Chairman—Stephen Lengel, 101 Island Brook Ave., Bridgeport, Conn.
1st Vice-Chairman—E. Stainano, 53 Gorham Ave., Hamden, Conn.
Secretary—J. E. Barker, 56 Roseley St., Bridgeport, Conn.
Treasurer—R. A. Lalli, R. A. Lalli Co., 247 Madison Ave., Bridgeport 6, Conn.
Chairman, Membership Committee—Robert Monde, Harris Co., Inc., 112 Hinsipiol Ave., Bridgeport, Conn.
Chairman, Program Committee—Leo Lefkowitch, 240 Parritt Ave., Bridgeport, Conn.
Technical Representative—Joseph R. Skibo, Farrel-Birmingham, Main St., Ansonia, Conn.

PRECISION FLAME CUTTING

Chicago, Ill.—On Friday night, April 22nd, the *Chicago* Section joined forces with the Calumet ASM Section for an outstandingly good meeting. A social period was held from 5:30 to 6:30 at Vogel's Restaurant in Hammond, Ind., and dinner was served family style beginning at 6:30 P.M. There was more roast beef, fried chicken and fried perch than any one could eat, although a number of the members tried their best.

AT THE MAY MEETING OF CHICAGO SECTION

A part of the crowd assembled to hear Levi Tarr discuss the recent advancements in "Inspection of Welds", at the May Meeting of Chicago Section

Mr. Tarr shown at the speaker's podium while delivering principal address

Following the dinner, A. J. Barkow [illegible], welding engineer of the Natural Gas Pipeline Co. of America, spoke on "Laying an Alaskan Pipeline." This was a most interesting subject with the slides showing the beautiful country that exists in our Alaskan territory. Mr. Barkow's slides also showed the rugged terrain through which the pipeline was layed, and during his discussion of the problems, he mentioned the various obstacles that had to be overcome.

The principal speaker of the evening was Howard B. Cary, welding superintendent, Marion Power Shovel Co., at Marion, Ohio. He spoke on "Precision Flame Cutting." The use of chain burning by the Marion Power Shovel Co., together with a well-integrated design, layout and template manufacturing operation permits the maximum utilization of steel plate. In one case the number of various thicknesses of steel was reduced from 16 to 5. Also efficiency of cutting is so great and design ingenuity is so well integrated that plate utilization resulting in scrap of less than 20% is becoming the practice.

The talk was very well presented and the large number of questions brought up from the floor reflected the wide interest in this topic.

Nearly 200 members and guests turned out for this meeting.

INSPECTION OF WELDS

Chicago, Ill.—The *Chicago* Section met in the auditorium, Peoples Gas, Light and Coke Co., on Friday evening, May 20th.

A social hour and dinner preceded the meeting and was held at Burke's Grill and Restaurant.

The premeeting movie covered the Pan American Road Race of 1954, and was a most entertaining and enjoyable session opening entertainment.

Speaker of the evening was Levi Tarr, chief inspector, Phillips Petroleum Co., who spoke on the inspection of welds. There were some rather interesting slides shown in addition to those of a strictly technical nature, and the number of questions following the talk showed the interest of the group in this subject.

The following officers and directors were elected for the 1955–56 season:

Chairman—Robert R. Lincoln, Air Reduction Sales Co.

1st Vice-Chairman—Jay Bland, Standard Oil Co.

2nd Vice-Chairman—Orville T. Barnett, Armour Research Foundation

Secretary—Edward Zahumensky, Taylor Forge & Pipe Co.

Treasurer—Howard C. Close, Machinery & Welder Corp.

Directors—

1 yr: Adam Bunk, Chicago Bridge & Iron Co.; Harry Comstock, National Cylinder Gas Co.; Ray A. Mueller, Crane Co.; W. A. Wilson, Cyclone Fence Div.

2 yr: E. C. Bailey, Commonwealth Edison Co.; R. L. LaBounty, Mississippi Valley Structural Steel Co.; P. T. McKinney, Union Carbide & Carbon Corp; H. K. Miller, Hobart Welder Sales & Service Co.

3 yr: W. S. Boedecker, the Bastian Blessing Co.; W. D. Miller, Coast Metals, Inc.; L. C. Monroe, *Welders' Digest;* C. Wigley, Westinghouse Electric Corp.

NONDESTRUCTIVE TESTING

Denver, Colo.—C. O. Penney, in charge of the Nondestructive Research Testing Department of the Denver & Rio Grand Western Railroad, was the speaker at the May 10th dinner meeting of the *Colorado* Section held in the Festival Room of the Oxford Hotel. Mr. Penney gave an interesting and instructive talk on the testing methods used on railroad units. One of the most interesting is the use of the electron microscope and spectroscope in analysis of the lubricating oil in Diesel engines; by which the condition, rate of wear, etc., is detected. Slides shown included examples of hidden flaws in rails and other equipment as well as spectrographs of lubricating oils and fuels.

The members were particularly interested in the information that the wear rate in engines is increased when the oil is replaced with new oil. Engines last longer when the old oil is left in and make-up oil is added only to maintain the required amount.

General discussion ended the meeting.

Before the meeting, a colored movie "Steel Across Water" was shown through the courtesy of the Bethlehem Steel Co. This film showed the construction of the bridge across Chesapeake Bay. The bridge is over four miles in length, curved and made up of truss spans cantilever and suspension spans—an interesting structure but not a welded structure.

PLANT TOUR

Dayton, Ohio.—The May meeting of the *Dayton* Section consisted of a plant visitation to Delco Products Division, GMC, Kettering Plant. Approximately 50 members and guests turned out for this tour.

The visitors were taken through this new modern plant in small groups and were shown a wide variety of manufacturing operations. This plant which makes a wide variety of industrial motors, generators and related products was moved from the center of Dayton and relocated in this one-story plant approximately three years ago. This enables the plant to specialize in the larger industrial motors while the Dayton plant continues with the small, fractional horsepower motors. A wide variety of operations re-

DETROIT SECTION QUIZZES EXPERTS

The four competing teams at the "Quiz the Experts Nite" held by the Detroit Section on April 1. Left to right: Anthony Wayne Section, Indiana Section, Toledo Section and Detroit Section. Moderator John Randall is at extreme right

The winning team from the Indiana Section. Left to right: M. G. Shaeffer, N. F. Bratkovich, J. R. Wirt and E. F. Holt

Roy L. Clark, Detroit Chairman, shown presenting the trophy to winner's Captain, Ray Wirt

quired for manufacturing these motors were viewed, including punching, nibbling, welding, die casting, machining, winding, dipping, etc.

ANNUAL QUIZ

Detroit, Mich.—On April 1st, the *Detroit* Section held their annual Quiz-the-Experts Night. Competing teams and participants were:

Detroit Section—Lloyd Dell, *Captain;* Jules Cruchet, G. E. Mortzenbecker and Ed Zulinski.

Indiana Section—J. R. Wirt, AWS, *Captain;* N. F. Bratkovich, Ed F. Holt and M. G. Schaeffer.

Toledo Section—J. W. Snell, *Captain;* John DeWitt, Lee Shanteau and James Kittle.

Anthony Wayne Section—H. M. Johnson, *Captain;* Carl Gaby, George Laws and K. H. Zimmerman.

A number of very good questions were put to the experts and, again, the Indiana Section was the winner, thus retaining the first-place trophy they had taken a year ago. Dinner was held in the dining room of the Engineering Society of Detroit. After the meeting, the Section was host to all for refreshments at the Park Shelton Hotel.

INERT ARC WELDING

Houston, Tex.—The *Houston* Section held its regular monthly meeting on Wednesday, April 27th, at the Ben Milam Hotel.

Due to conditions beyond his control, the guest speaker was unable to attend. Warren G. Gumm AWS, district engineer for Linde Air Products Co., spoke in his place. The subject of his talk was "Inert-Gas Metal-arc Welding of Mild Steel." Mr. Gumm's talk was very good and enjoyed by all. Ninety-three members and guests attended the meeting.

SOCIAL MEETING

Houston, Tex.—The annual social meeting of the *Houston* Section was held May 20th at the Grand Prize Grove.

Installation of new officers and directors was held; they are:

Chairman—H. H. Wehner, Jr., Hughes Tool Co.

1st Vice-Chairman—P. D. Morgan, Industrial Welding Supply Co.

2nd Vice-Chairman—Roy Pringle, Air Reduction Sales Co.

Secretary-Treasurer—W. C. Cox, General Electric Co.

Asst. Secretary-Treasurer—E. R. Wyckoff, Linde Air Products Co.

Directors—James Earthman, Wyatt Metal & Boiler Works; Victor A. Thompson, Mosher Steel Co.; Charles Dick, Todd Shipyards; T. J. Kegg, Jr., Champion Industrial Sales; W. G. Gumm, Linde Air Products Co.; and George Demees, Welders Supply Co.

A good time was had by all.

AUTOMATION IN WELDING

Beaumont, Tex.—Sabine Division of the *Houston* Section held its regular monthly dinner meeting on Thursday, April 27th, at the Edson Hotel.

Before-dinner entertainment consisted of the showing, through the courtesy of the Eastern Air Lines, of an interesting film entitled "Flying Fisherman's and Hunter's Club."

Technical speaker was Anthony Pandjiris AWS. His subject was entitled "Weldmation." Mr. Pandjiris dealt briefly with the early beginning of automatic electric arc welding. The problems of manipulation of parts necessary to automatic welding were discussed. Problems relating to automatic welding not found with manual arc welding and a cost comparison were drawn between auto and manual arc welding to show the advantages and disadvantages. Slides were used to illustrate the talk.

HORTONSPHERE

Des Moines, Iowa.—For *Iowa's* March meeting, held on the 17th, Christian Arne of Chicago Bridge & Iron Co. entertained and instructed a large audience on the building of the Hortonsphere for use in atomic energy experimentation programs. By use of slides and motion pictures, the development and construction details were unfolded in chronological order from beginning to end of this magnificent project.

Preceding Mr. Arne's speech, Lt. Huffsmith of the Des Moines Air Defense Filter Center outlined briefly the purpose and duties of our Air Defense Program in the Iowa area.

TOOLING

Des Moines, Iowa.—On April 21st, *Iowa's* Section met at the Kirkwood Hotel in Des Moines to hear Cecil C. Peck AWS give a talk on "Tooling for Mechanized Welding." Accompa-

nied by many slides for display of many different applications, Mr. Peck said there are four necessary requisites to be able to design fixtures for welding and they are: "(1) Be a mechanical engineer; (2) Be a electrical engineer; (3) must have been a welder; and (4) crazy!" Each design, Mr. Peck relates, is different from the last one and presents a completely different set of conditions to cope with. An excellent sized audience was in attendance.

TOM COLLINS' NIGHT

Kansas City, Mo.—The final meeting of the year for the *Kansas City* Section was held on May 12th at Holiday House with the noted humorist and philosopher, Tom Collins, as the featured speaker. Mr. Collins is the publicity director of the City National Bank and Trust Co. of Kansas City, Mo.; he has had probably more repeat requests than any other speaker in the United States. At least 70% of his more than 5000 talks have been second or more appearances. As usual, he gave a very timely and humorous talk.

ANNUAL STAG

New York, N. Y.—The final meeting of the year for the *Long Island* Section was the annual Stag-Entertainment meeting, held jointly with the *New York* Section, at the Building Trades Club, 2 Park Ave., New York City, on Thursday evening, May 12th. The affair was completely sold out—350 members and friends attending. This meeting, if anything, surpassed previous stag meetings and a good time was had by all.

The new officers and executive committee members for the 1955–56 season were announced by the retiring chairman, Ed Moles. The Section was pleased to present a Past-Chairman Pin to Ed, who was the first chairman of the Section and initiated the organization of the Long Island Section.

The Executive Committee for the 1955–56 season will be comprised of the following members:

Chairman—Charles W. Berry, General Welding Supply Co., Inc., Mineola, L. I.

1st Vice-Chairman—Robert M. Platz, Fairchild Engine & Airplane Corp., Farmingdale, L. I.

2nd Vice-Chairman—William C. MacLaury, Grumman Aircraft Engineering Corp., Bethpage, L. I.

Secretary - Treasurer—Albert A. Strickland, Linde Air Products Co., New York City

Members at Large—

1-yr term: John Alvar, Grumman Engineering Corp., Bethpage, L. I.; Joseph Jungbluth, Rayno Distributors, Inc., Brooklyn, N. Y.; Herbert Leary, Whitehead Metal Products, Inc., New York City; Joseph Schaad, Weld-Arc Sales & Supplies, Inc., New York City

2-yr term: Anton Angiulo, Nassau Suffolk Welding, Inc., Bellmore, L. I.; Keith W. Berry, General Welding Supply Co., Inc., Mineola, L. I.; H. Robert Gordon, R. E. F. Manufacturing Corp., Mineola, L. I.; Norbert L. Kopchinski, Grumman Aircraft Engineering Corp., Bethpage, L. I.

WELDED HONEYCOMB STRUCTURES

San Diego, Calif.—The Aircraft and Rocketry Welding Panel of the *Los Angeles* Section, held a technical session and dinner meeting on May 6th at the new swank Mission Valley Country Club, located in San Diego's beautiful Mission Valley. This was the A& RWP'S fourth venture in bringing together the San Diego members, who are without a local chapter, the Long Beach members and the Los Angeles members for a grand meeting.

E. E. "Tiny" Hardesty and Howard E. Roberts presented a very enlightening paper on the subject of "Resistance Welding of Stainless Steel Honeycomb Structures."

Mr. Roberts, general manager of Fairchild's American Helicopter Division of Manhattan Beach, Calif., introduced the subject matter and Mr. Hardesty presented the technical aspects of resistance brazing and welding development work done at his Research Plastics Plant in Costa Mesa, Calif.

Both presentations were very well done. Mr. Roberts described the thermodynamic and aerodynamic heating problems with which our future planes are to be confronted with when reaching air speeds in excess of Mach 3. He then compared the various mechanical properties of three widely used aircraft materials, SAE 4340, Stainless W and Inconel X, plus a relatively new material, RC-130B titanium alloy. As the comparisons proceeded, it became apparent that stainless steels in the full hard condition were best suited for high-temperature airframe structures. This was based on stiffness efficiency, fabrication know-how and material cost. Except for its low modulus of elasticity, titanium also looked promising; however, its present cost is too prohibitive for economical usage.

Mr. Hardesty described various cursory joining techniques which were explored in an attempt to find a practical joining process which could utilize fully hardened stainless steel.

Research development of a resistance roll welding process coupled with a proprietary base metal surface preparation finally produced a technique which could be used to join thin or thick sheet facings to very thin square cell honeycomb core.

Core shear strengths as high as 450 psi have been attained from beam tests. An average core shear of 390 psi at room temperature and 250 psi at 800° F are easily obtained at the present stage of development.

ANNUAL SPRING PARTY

South Bend, Ind.—The *Michiana* Section held an annual spring party and business meeting on May 19th at Buysses Hall in South Bend.

The election of the following officers for the 1955–56 season was announced:

Chairman—Lloyd Ebert, Michiana Products, Michigan City, Ind.

Vice-Chairman—Jack Robinson, Bendix Products Division, South Bend, Ind.

Treasurer—J. A. Miller, Bendix Products Division, South Bend, Ind.

Secretary—W. G. Fassnacht, Bendix Products Division, South Bend, Ind.

Board of Directors—Tom Wilhelm, Edwards Iron Works, South Bend, Ind.; Leo Cuthbert, Whirlpool Corp., St. Joseph, Mich.; Harry Hale, Bendix Products Division, South Bend, Ind.

A program of motion pictures and games, during which "wieners" and beer were served and prizes were awarded, completed the meeting.

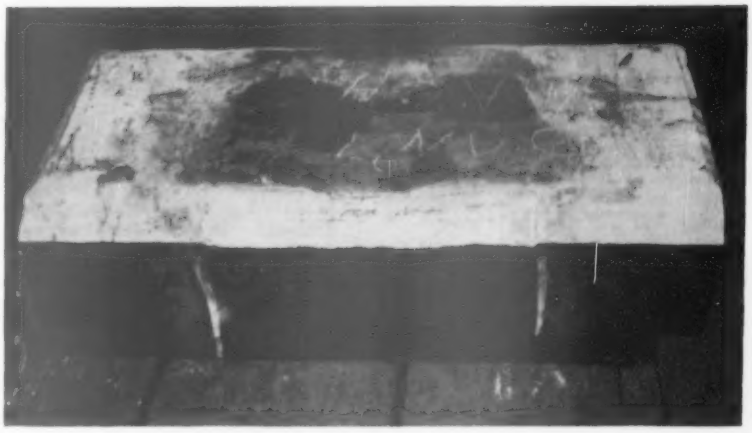
CAST-WELD DESIGN

Newark, N. J.—The regular monthly meeting of the *New Jersey* Section was held on Tuesday evening, April 19th, at the Essex House in Newark. Dinner with approximately 120 members and guests followed a meeting of the Executive Committee. A short film entitled "Man on the Sand" was shown following the dinner.

Chairman Kenneth Koopman opened the technical meeting at 10:00 P.M. and introduced the speaker George K. Dreher. Mr. Dreher is secretary of the Steel Founders' Society of America. His talk on cast-weld design and application was illustrated with slides and was followed with numerous questions from the floor.

Extending die life with Crucible REXWELD. At points of greatest wear, the die face is undercut to a depth of ¼" below finish dimensions. It is then preheated to about 600F and hardfaced with REXWELD VT, using approximately twenty pounds of electrodes. The die is then cooled in air, and its surfaces ground to size. It is then ready for the press.

This REXWELDED die is shown after 11½ turns of continuous operation. During this period 155,000 pounds of steel were forged, 80% of which were *Superalloys S-816 and A-286*. At this point the press foreman reported a slight depression in the die face. *It had already given 400% greater service than had been experienced from untreated dies.*



Crucible REXWELD hardfacing rods keep dies in service 4 times longer...

This tungsten-bearing austenitic stainless steel die is designed for forging high-speed and high-alloy steels on a 1000-ton press. Normally, after only 1 to 3 eight-hour turns of production, it must be removed from the press and its surfaces replaned. And successive planing operations quickly reduce the die's thickness to below minimum limits, and it must be scrapped.

But by REXWELDING as shown above, die life is extended 400% or more. For REXWELD adds a surface that is even tougher, more wear-resisting than the original die material – and you can REXWELD again and again.

So when you have an application where surfaces must withstand wear or abrasion, try REXWELD. Your nearby Crucible warehouse has REXWELD low-hydrogen coated electrodes and bare rods in the sizes and grades you need. *Crucible Steel Company of America, Henry W. Oliver Building, Pittsburgh 22, Pa.*

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America

BUFFALO SCENE OF "BATTLE OF THE SECTIONS"

A few of the guests shown during the dinner which preceded "Battle of the Sections." Niagara Frontier Section acted as host

Moderator Charlie Jennings addressing the audience. Niagara Frontier team is at left. F. L. Rodgers, Chairman of host Section, is at right

The four judges who had the difficult, though pleasant, task of selecting winners are at left. Syracuse Section team is at right

BUSINESS-SOCIAL MEETING

Newark, N. J.—The regular monthly meeting of the *New Jersey* Section was held on Tuesday evening, May 17th, at the Essex House in Newark, N. J.

The Executive Committee meeting was held at 5:15 P.M. followed by dinner at 6:30 P.M., with approximately 120 members and guests attending.

Chairman Ken Koopman opened the regular meeting at 8:15 P.M. and introduced the new officers for the coming year:

Chairman—J. Riley, M. W. Kellogg Co.

Vice-Chairman—L. Detlor, Esso Research and Eng. Co.

Secretary—E. DiLiberti, Air Reduction Sales Co.

Treasurer—J. Hila, Foster Wheeler Corp.

Executive Committee (two-year term)—J. Bagley, Esso Standard Oil Co.; M. Hoffman, Todd Shipyards Corp.; R. Hubbard, Magar Car Corp.; T. Smith, Bethlehem Steel Co., Shipbuilding Div.; R. Thornton, Metal & Thermit Corp.

After a brief business session, H. Hughey, program chairman, introduced Sgt. R. J. MacCullouch, speaker for the evening. Sgt. MacCullouch is with the Passaic Police Department where he has achieved championship honors in competition for outstanding use of the pistol. Through a live demonstration, he showed some of the methods and fine points that make for successful training results. His demonstration was acclaimed by those present.

The demonstration was followed with the usual get-together and refreshment period.

BATTLE OF THE SECTIONS

Buffalo, N. Y.—At the last regular business meeting of the 1955 season, the *Niagara Frontier* Section held its annual "Battle of the Sections" on April 28th.

Participating Sections were Syracuse, Canada, Olean-Bradford and Niagara Frontier. Each Section was represented by three experts. The judging staff consisted of one representative from each of the Sections plus an impartial judge. C. H. Jennings, past national president, served as moderator.

Brain-tickling questions were prepared in advance on the following subjects: manual arc welding, oxy-acetylene welding and cutting, brazing, inert gas welding, submerged arc welding, resistance welding, electricity and electric welding equipment, inspection and testing, welding metallurgy, safety, miscellaneous.

To eliminate differences of opinion concerning correct answers, the official answer to each of the questions was in the hands of the judges and the moderator. In rebuttal, each Section ran the chance of winning or losing up to the full point value of the question.

As in previous years, this proved to be one of the outstanding meetings of the year. All Sections participating were backed by good representation from their respective districts, and were cheered and actively supported by their backers.

The Niagara Section took a substantial lead in the first round and it looked like they had the championship in the bag. In the succeeding rounds, however, our Canadian friends, Syracuse and Olean-Bradford came back strong, and the battle was neck and neck going into the home stretch. In the final round, the slow-starting Olean-Bradford team, ably led by Michael Robertson, swept aside all competition to win the grand prize and the 1954–55 championship. This made it two in a row for the "South of the Border," Olean-Bradford boys, since they had also captured the 1953–54 championship.

Licking their wounds, the losing teams good naturedly agreed that they would have to devote more time to their textbooks during the coming year if they were to topple this crack team next year.

Charles Jennings turned in his usual stellar performance adlibbing between rounds with well-chosen quips, and keeping the rousing throng of visitors under control during the contest.

ANNUAL MEETING

Minneapolis, Minn.—The *Northwest* Section ended a most successful year with their annual meeting Monday, May 16th, in the Lodge Room of the Covered Wagon in Minneapolis. Eighty-five members attended to elect new officers and see the nontechnical films offered for their enjoyment.

The following officers were elected

Chairman—C. M. Clogston, Welding Engineer, Northern Ordnance, Inc.

Vice-Chairman—A. P. Demmer, Supervisor, Technical Sales, Air Reduction Sales Co.

Secretary-Treasurer—Lillian K. Polzin, Minneapolis Chamber of Commerce

C. M. Clogston

Executive Committee—

John Anderson, Owner, Minnesota Welding Supply Co.; Donald Bauer, Owner, Bauer Welding & Metal Fabricators; Paul Benjamin, Foreman, Great Northern Railway Co.; W. E. Coleman, Field Sales Representative, Linde Air Products Co.; Marshall Ford, District Manager, Lincoln Electric Co.; Roger D. Griffis, Sales Representative, H. R. Toll Co.; A. H. Hanson, Superintendent, St. Paul Structural Steel Co.; L. T. Kenny, President, Kenny Boiler & Mfg. Co.; Warren F. Logemann, Chief Engineer, Brown Steel Tank Co., B. J. Mankowski, Factory Representative, Smith Welding Equipment Corp.; John Markwell, Instructor, Welding Dept., Dunwoody Industrial Institute; L. A. Morehead, Sales Engineer, National Cylinder Gas Co.; Howard Nielson, General Foreman, Paper, Calmenson & Co.; Sydney H. Palmer, Vice-President, Twin City Welding & Mfg. Co.; Paige Reinhardt, Steel Supt., St. Paul Foundry & Mfg. Co.; R. H. Schleuder, Production Assistant to Works Manager, Electric Machinery Mfg. Co.; and F. W. Scott, Manager, Electrode Plant, Marquette Mfg. Co.

BATTLE OF THE SECTIONS

No regular local meeting of the *Olean-Bradford* Section was held in April due to the fact that the members of this Section were invited by the Niagara Frontier Section to participate in their annual "Battle of the Sections." A complete write-up of this event is given in the Niagara Frontier Section report.

ANNUAL DINNER PARTY

Philadelphia, Pa.—The annual dinner party of the *Philadelphia* Section was held on May 21st at the Engineers Club. As in the past, this gala annual affair was a huge success and was well attended by some 175 members and guests.

Frank Cunningham, AWS, Chairman of the Arrangements Committee, did an excellent job. A. N. Garcia did his usual good job on decorations, and also rendered some vocal selections which were enjoyed by the members and guests.

Prior to the delicious roast beef dinner, cocktails were served for an hour, affording a good time for meeting and greeting members, guests and their ladies. After the dinner, dancing was enjoyed until 1:00 A.M. to the music of Marty Kramer's orchestra.

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The *Philadelphia* Section announces the election of the following officers for the 1955–56 season:

Chairman—E. E. Goehringer, Lincoln Electric Co., 204 Baltimore Pike, Springfield, Pa.

1st Vice-Chairman—A. M. Garcia, Morris Wheeler & Co., Inc., Fox St. and Roberts Ave., Philadelphia 29, Pa.

Secretary—Byron D. Gates, The Budd Co., Red Lion Plant, Red Lion & Verree Rds., Philadelphia 15, Pa.

Treasurer—L. D. T. Berg, Areway Equipment Co., 49th & Grays Ave., Philadelphia 43, Pa.

NEWLY ELECTED OFFICERS

Pittsburgh, Pa.—The *Pittsburgh* Section announces the election of the following officers for the 1955–56 season:

Chairman—Ludwig Adams, Pittsburgh-Des Moines Co., Neville Island, Pittsburgh 25, Pa.

1st Vice-Chairman—H. L. Anthony, Mellon Institute, 4400 Fifth Ave., Pittsburgh 13, Pa.

Secretary-Treasurer—J. F. Minnotte, Minnotte Brothers Co., Hays, Pittsburgh 7, Pa.

Chairman Membership Committee—J. H. Patterson, Linde Air Products Co., 644 Oliver Bldg., Pittsburgh 22, Pa.

Chairman, Program Committee—H. E. Cable, 1124 Cornell Rd., Pittsburgh 5, Pa.

Technical Representative—D. H. Marlin, 634 Forest Ave., Bellevue, Pittsburgh 2, Pa.

STRUCTURAL WELDING

Portland, Ore.—An excellent illustrated discussion on the New Specifications and Practices for Structural Welding was given by LaMotte Grover AWS, Air Reduction Co., New York, at the May 17th meeting of the *Portland* Section held at the Heathman Hotel.

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The *Portland* Section announces the election of the following officers for the 1955–56 season:

Chairman—George A. Conner
1st Vice-Chairman—W. L. Wyman
Secretary—Earl Bobbitt
Treasurer—L. Kissler

PLANT TOUR

Seattle, Wash.—The April 14th dinner meeting of the *Puget Sound* Section consisted of an interesting short talk by Eric Kinnaird AWS, of the Pacific Car & Foundry Co., Renton, Wash., regarding the scope of operations of Pacific Car; and a colored motion picture on the manufacture and use of their products. This was followed by a well-conducted tour of the company's forge shop, steel shop and refrigeration car assembly lines.

SYMPOSIUM

Flint, Mich.—On May 12th, the *Saginaw Valley* Section sponsored a day-long Symposium on Automatic Arc Welding Processes. A speakers' reception was held at the Durant Hotel the evening prior to the meeting and was attended by the guest speakers, symposium session chairmen, section officers and equipment demonstrators. Designed as a get-acquainted session, it more than fulfilled its purpose. Hors d'oeuvres and refreshments were served.

The morning and afternoon technical sessions were held in the Grand Ballroom of the Durant Hotel. The morning session was capably conducted by Simon Fisher of National Electric Welding Machine Co. This session featured papers by:

Robert Wilson of Lincoln Electric Co., who spoke on the "Fundamentals of Submerged Arc Welding." Mr. Wilson's talk covered the basic problems encountered in this process and how they may be overcome.

H. D. Mann of Air Reduction Sales Co., whose paper covered the "Fundamentals of Consumable Electrode Inert Arc Welding." Mr. Mann's paper covered the use of the various gases and gas mixtures used in this process. A high-speed film showing the electrode burn-off with different gases and polarities was of special interest.

R. W. Tuthill of General Electric, who spoke on "CO_2 Gas and Its Application." Mr. Tuthill's talk dealt with the use of a rising slope power source and carbon dioxide gas as a shield.

The luncheon coffee talk was given by Preston Mann who gave a very humorous account of his experiences while training dogs in the Army during World War II.

The chairman of the afternoon session was J. N. Alcock, of the Saginaw Welding Supply Co., and president of the NWSA. The speakers in his panel included:

Harley Orr of Hobart Brothers Co., who spoke on "Constant Voltage Welder Application to Automatic Welding Processes." His very interesting talk included illustrations of

OFFICERS AND SPEAKERS AT AUTOMATIC ARC WELDING SYMPOSIUM

R. W. Tuthill, S. Fisher, Session Chairman, R. Wilson, H. D. Mann

Front Row: Simon Fisher, W, E. Moehring, Section Chairman; Back Row: W. F. Williams, Symposium Chairman, J. N. Alcock, H. W. Longair, I. S. Makulinski, Section Vice-Chairman

H. W. Longair, Session Chairman, G. K. Willecke, J. N. Alcock, Session Chairman, H. Orr

various constant voltage welder applications.

G. K. Willecke of Miller Electric Manufacturing Co., whose paper covered the "Recent Developments in Rectifier Welder Design." Mr. Willecke discussed the various problems encountered in designing rectifier type welders to conform to the various ampere-voltage curves and made a few interesting comments on what the future holds in the inert arc welding field.

N. C. Schreiner of Linde Air Products, who spoke on "Multiple Electrode Welding by the Submerged Arc Process." Mr. Schreiner's talk covered thoroughly the various facets of this subject. Various industrial applications were discussed.

A very lively question-and-answer period was held following each session.

The dinner meeting and evening demonstration session was held at General Motors Institute. H. W. Longair, the evening chairman, introduced the guest speaker, G. R. Cowing, president of General Motors Institute. Mr. Cowing briefly outlined the subjects comprising the core of the engineering curriculum. He reviewed the history of the welding program at the Institute and the philosophy behind it. He also suggested several ways in which the Welding Society can aid in maintaining closer coordination between schools and industry.

"First," Mr. Cowing said, "The Welding Society can be the vehicle through which faculty members in the various skills can interchange ideas, participate, and continue their self-improvement. I understand that you have an educational committee. This committee should establish a liaison between those responsible for instruction in welding technology and the Society. Through your meetings and through your publications they can be advised of trends and new developments.

"In the second place, I suggest that students who join your Society be encouraged to remain members. The critical years in the transition from student status to full professional status are those two to five years following graduation. In those years the student is usually so vitally concerned with establishing a home and becoming a member of his employing organization that oftentimes he permits his professional affiliations to lapse. Your Society might promote through its meetings the participation of some of these younger members of the profession.

"Third, an active interest on your part would support the training activities in those schools where welding technology is offered. Our own institution affords an illustration. In our courses for engineering students the application of welding fundamentals is shown by means of actual plant procedures and problems rather than by theoretical or academic ones. This not only increases the value of our instruction but also adds to the man's ability to solve future problems. This tie-in that exists between welding fundamentals and applications is made possible through the excellent cooperation and close relationship which the Institute maintains with the actual users of its product—the division, the plants and the dealers of General Motors.

"Finally, in your relations with schools, remember that the instructors who are producing the major part of the educational foundation for the engineers of the future are not necessarily those engaged directly in instruction in welding technology. Make sure that those engaged in teaching the physical and engineering sciences have an opportunity to see the developments you are making in order that they may lay a better foundation in those sciences for the future application the graduate may have to make to your field."

Tours of the Institute's facilities and welding process demonstrations were held concurrently. Live demonstrations were made of the inert gas processes using carbon dioxide, argon and activated wire. Constant potential submerged arc welding was shown along with the automatic arc voltage control process. Simulated plow points were welded using the multiple electrode process and alloy additions in the flux.

Semiautomatic hard surfacing was also demonstrated using both magnetic alloy flux and composite wire.

Approximately 150 people attended each of the sessions.

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Saginaw Valley Section announces the election of the following officers for the 1955–56 season:

Chairman—Irving Makulinski, 610 W. Philadelphia Blvd., Flint 5, Mich.

1st Vice-Chairman—Robert F. Woollard, Route 1, Freeland, Mich.

Secretary—Joe Stanulis, 3130 S. Jefferson Ave., Saginaw, Mich.

Treasurer—W. F. Williams, 2319 Covert Rd., Flint, Mich.

EARTH MOVING EQUIPMENT

Alviso, Calif.—J. E. Richter [illegible], of the Wooldridge Manufacturing Division, Continental Copper & Steel Industries, was the guest speaker at the April 26th meeting of the *Santa Clara Valley* Section held in Vahl's Club in Alviso. Mr. Richter's subject was "Welding and Fabrication of Earth-Moving Equipment." Mr. Richter first became connected with the Wooldridge Manufacturing Division in 1938. Since 1947 he has served as chief engineer and has direct supervision over product engineering, shop equipment, jigs and fixtures, and inspection.

RICHTER IS PRINCIPAL SPEAKER AT APRIL MEETING OF SANTA CLARA VALLEY SECTION

Shown facing camera during dinner which preceded meeting are (left to right): Mike Sebastian, Francis Bell, Jack Garrels, Treasurer of Section, Fortune Masdeo, Second Vice-Chairman, Mansfield Griffiths, Chairman, J. E. Richter, Speaker, Ed Strohmair. Ray Townsend is at lower right-hand corner

Mr. Richter is shown here during his address on welding and fabrication of earth-moving equipment

ANNUAL MEETING

Miami, Fla.—The annual meeting and buffet supper of the *South Florida* Section was held on May 18th in the Tap Room of the Regal Brewery.

After-dinner speaker was the local prominent "Dutch" Sulzberger, club speaker and lecturer, and head of an insurance firm. Mr. Sulzberger's talk was on the lighter side, humorous and very entertaining; it was well received by the audience and roundly applauded.

The chairman of the nominating committee, Mr. Wingerter, announced the election of the following officers:

Chairman—Al Thompson
1st Vice-Chairman—Paul Greenfogel
2nd Vice-Chairman—Robert Banning
Secretary—T. Berg
Treasurer—Leo R. Riedy

ELECTION OF OFFICERS

Sheffield, Ala.—The *Tri-Cities* Section announces the election of the following officers for the 1955–56 season:

Chairman—Trewhitt H. Shields, 1301 30th St., Sheffield, Ala.
1st Vice-Chairman—Robert P. Coker, 518 W. Tuscaloosa St., Florence, Ala.
Secretary—Norman R. Goode, Reynolds Metals, Parts Division, Box 791, Sheffield, Ala.
Treasurer—Leroy Feilds, Post Welding Supply Co., 2901 Jackson Highway, Sheffield, Ala.
Chairman, Membership Committee—John Burke, Lake Dr., Route 2, Killen, Ala.
Technical Representative—Fred Eckert, 1303 30th St., Sheffield, Ala.

ANNUAL MEETING

Washington, D. C.—The *Washington* Section held its annual meeting and Ladies Night with an attendance of 245 members and guests on Tuesday, May 3rd, at the Old Georgetown Hospitality Hall of the Christian Heurich Brewery. Highlights of the evening were the presentation of Past-Chairman's Pin to Bernice M. McPherson, chairman of the Washington Section; installation of new officers; the main address of the evening by former Congressman Calvin D. Johnson; and a dance.

Harry Ingram, formerly a member of the Executive Committee of the Washington Section and now located

WITH THE WASHINGTON SECTION AT THE MAY 3RD MEETING

(Left to right): Mrs. Merton F. Duvall, Dr. Morgan Williams, National Bureau of Standards; Merton F. Duvall, Mayor of Gaithersburg, Md.; Joe Magrath, National Secretary of American Welding Society; Mrs. Bernice M. McPherson, Chairman of the Washington Section; R. Alden Webster, Incoming Chairman; Mrs. Godfrey, wife of Michael Godfrey, Program Chairman; Mrs. Everett, Richard Everett, Immediate Past Chairman; Mr. Basil of Lincoln Electric Co. of Baltimore; and Howard Montaigne of District Oxygen Co.

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offer a group of tested performance features

COMPARE THE VALUE

Prove the superiority of General Electric a-c welders to yourself. Just check this feature-by-feature comparison of G-E welders with four other popular makes. You'll see that only G-E provides you with *all* these features . . . for top performance over a long lifetime of service.

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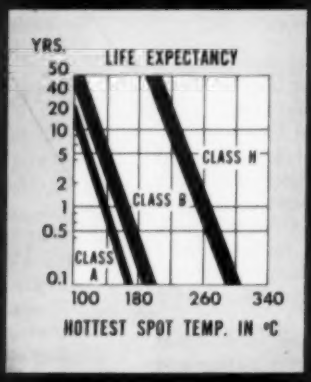

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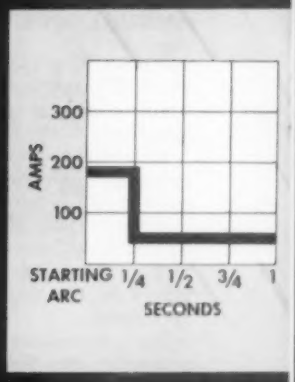

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GENERAL ELECTRIC	✓	✓	✓
MANUFACTURER "A"			✓
MANUFACTURER "B"	✓	○	
MANUFACTURER "C"			✓
MANUFACTURER "D"			

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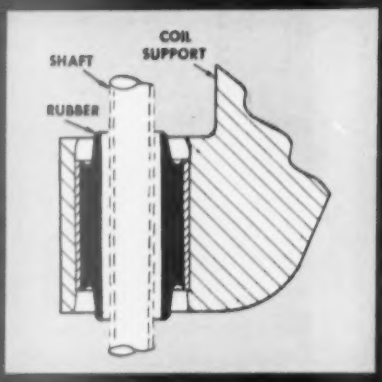
Four husky ratings—295, 300, 400, and 500 amps; feature high open-circuit voltage.

ARC STABILIZERS assure steady arc, faster welding, fewer "patch ups."

LARGE CURRENT SCALE can be read easily from the job, expanded in low range for extra-fine accuracy.

EASILY REMOVABLE SIDE COVERS: only three screws have to be removed for quick access to inside.



FLOATING-COIL MOUNT eases current adjustment minimizes friction, noise, wear and vibration.

GENERAL ELECTRIC

in New York, made the presentation of the Past-Chairman's Pin "to the only woman in the AWS to be so signally honored—Bernice M. McPherson—who has held the position of member of the Executive Committee, secretary and chairman of the Washington Section."

Installation of R. Alden Webster as chairman of the incoming year was made by Richard Evert, past chairman.

The remaining officers for the 1955–56 season were announced as follows:

Vice-Chairman—Dr. M. L. Williams
Secretary—K. Davis
Treasurer—R. E. Lyons
Executive Committee—
Term expires 1957:
Bernice M. McPherson, Capt. R. D. Schmidtman, M. F. Godfrey, T. W. Bowron, A. L. Tarr and E. W. Eschbacker
Term expires 1956:
R. W. Evert, W. J. Hill, F. C. Bailey, M. Hayase, G. G. Luther and F. W. Davis

The evening began with a buffet supper and was concluded with dancing.

AT THE SPRING WELDING CONFERENCE OF WESTERN MICHIGAN SECTION

Standing (left to right) J. R. Stitt, Detroit, Mich., District No. 6 Director; Robert E. Kemp, American Seating Co., Grand Rapids, Mich.; Roy Clark, Uniflex Cable Co., Detroit, Mich.; John Mikulak, Worthington Corp., Harrison N. J.

Seated (left to right) Ernst Duesing, Conference Director, Grand Rapids, Mich.; John H. Blankenbuehler, Troy, Ohio, District No. 5 Director; Paul Wagner, Battle Creek, Mich., Section Chairman

MOVIES

Springfield, Mass.—The April 12th meeting was the final meeting of the season of the *Western Massachusetts* Section. Two very beautiful and interesting movies were shown entitled "Canadian Pattern" and "Canada's Tackle Busters." These were shown through the courtesy of the Canadian Pacific Railway Co. They covered all the principal cities starting on the east coast and ending on the west coast. All points of interest were shown and also scenes along the railroad in the mountain which were very colorful. The picture, "Tackle Busters," was a fishing scene which was of great interest to anyone with any sporting blood at all. The picture featured two elderly men competing for the prize fish of the day, and of course the freckle-faced boy with his hickory pole and pet cub-bear fishing off the bank walked off with the prize fish. Regardless of age, it was enjoyed by all.

ANNUAL WELDING CONFERENCE

East Lansing, Mich.—The annual Spring Welding Conference of the *Western Michigan* Section was held in cooperation with the Engineering Department of the Michigan State College on April 15th on the College Campus in East Lansing, Mich. Between 70 and 80 members and guests attended the one-day meeting.

The conference was opened with a short talk by the district director of the section, J. R. Stitt of Detroit, Mich.

The two morning sessions featured Aluminum Welding and Product Design for Welding.

Robert Kemp AWS, welding engineer of the American Seating Co., gave an illustrated lecture on Resistance Welding of Aluminum. Peter Stern of the Reynolds Metals Co. in Louisville, Ky., assisted in answering questions on aluminum welding. Charles Bruno AWS, chief welding engineer of the Reynolds Metals Co., who was scheduled to conduct the first technical session, became seriously ill just a few days before the conference. Eric Guenther acted as chairman of the session.

John Mikulak AWS, assistant to the vice-president, Worthington Corp., discussed principles, facilities and costs involved in the design of welded structures and machine components. The lecture was illustrated by slides. Chet Vorhorst of Grand Rapids, Mich., introduced the speaker and acted as chairman for the session.

Between the first and second morning session, John H. Blankenbuehler, Director of District No. 5, in a short address to the attending members and guests, stressed the importance of welding and the wealth of information made available at such technical meetings.

In the afternoon Ralph R. McNitt AWS, senior production engineer at Oldsmobile, Lansing, Mich., was introduced by Vic Sbordon, chairman of the afternoon session. Mr. McNitt itemized and discussed the various types of welding being utilized in the manufacture of Oldsmobile automobiles. After the lecture the whole group went to "Oldsmobile" to see the actual application of deep flux, mash seam, roll seam, spot, projection, inert arc welding, slope control welding and induction brazing.

The day ended with a dinner given for the attending officers, the speakers and their wives.

Idealarc Machines being used by the W. Horace Williams Company, Inc., New Orleans, Louisiana, in the production of offshore drilling platforms.

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Cost reductions you can duplicate now by using industry's greatest cost-cutting twins... IDEALARC and JETWELD

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One machine gives him *both* AC and DC welding.

With AC current, he can use *Jetweld* iron powder electrodes for top speed on down hand work.

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On both AC and DC, he selects the best type arc, "soft" arc or "forceful" arc.

INVESTIGATE IDEALARC for your operations. Lincoln can show you how you can make similar reductions in the cost of welding. Write for Bulletin 1343 today.

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ATLANTA

Cato, Thornwell H. (B)

BIRMINGHAM

Allen, R. H. (B)
Stockton, J. L., Jr. (B)

BOSTON

Baker, Fred W., Jr. (B)
Borden, Fred (B)
Cumings, Waldo (C)
Goldman, Joseph (B)
Hall, Albert S. (B)
Indresano, Delfino (C)
Sweatman, Maurice S. (B)
Tilton, F. Elwin (B)

CANADA

McCurdy, Leslie Briggs (C)

CHICAGO

Beebe, Emmett R. (B)
DeAngeles, Ron (B)
Jaksha, Fred W. (C)
Lanzendorf, John J. (B)
Pierce, John M. (B)
Sell, Robert F. (C)
Skeie, Kermit (B)
Smith, Raymond J. (C)
Sullivan, J. F., Jr. (B)
Zimmerman, E. J. (B)

CINCINNATI

Beck, F. H. (C)
Garrett, Ollie R. (C)
Hoppin, George S., III (C)
Keeney, James H. (C)
Kelly, Earl L., Jr. (C)
Root, Charles W. (C)
Stephan, Hans R. (B)

CLEVELAND

White, George William (B)

DALLAS

Helgerson, H. A. (B)
Tanner, John L. (C)
Thompson, John M., Jr. (B)

DETROIT

Bernardi, James T. (B)
Bossche, John V. Vanden (B)
Cullen, John L. (B)
Curran, George F., Jr. (B)
Dean, Royal D. (B)
Jackson, Robert (B)
Muszynski, Joseph E. (C)
Savage, Russell George (B)
Simon, H. Nelson (B)

FOX VALLEY

Johnson, John M., Jr. (C)

HARTFORD

Albert, Henry Jos. (B)

HOLSTON VALLEY

Bailey, Perry S. (B)

HOUSTON

Averbeck, Albert A. (C)
Beasley, Ralph T. (C)
Clark, Paul J. (B)
Connell, Alvin Herbert (B)
Hartman, David E. (D)
Heimer, Erwin (B)
Olson, John E. (D)
Richardson, Ralph L. (C)
Rounds, Jerome A. (C)
Sommerville, John N. (C)
Steph, Richard Robinson (D)

INDIANA

Fitting, Douglas (C)
Reese, Harry L. (B)

IOWA

Murray, Eugene P. (B)
Smith, Donald C. (C)

IOWA-ILLINOIS

McDowell, Clement (B)

KANSAS CITY

Claus, Fred R. (B)
Goodwin, George (C)
Kuhar, A. J. (B)
Mischke, Rudolph F. (B)

LONG BEACH

Alt, Jack (C)

LONG ISLAND

Carroll, John Joseph (B)
De Lello, Anthony (B)
Drewes, Luer (B)
Howard, Charles Edward (C)
Pevey, Alvin (B)
Richter, Frank W. (C)
Scheyer, Bob L. (B)

LOS ANGELES

Henricks, John (B)
Way, William James (C)
Zierer, Robert M. (D)

MADISON

Cafferty, Michael (D)
Jewell, Floyd (C)
Romare, Ernfred J. (B)

MICHIANA

Gyuriak, Steve (C)
Lyerla, Everette Lee (C)

MILWAUKEE

Eberle, Gene T. (C)
Hinrichs, John F. (D)

NEW JERSEY

Bisbing, Paul W. (B)
Cason, Edward B., Jr. (C)
Goodman, William P. (B)
Henry, Dean (B)
Johnson, George R. (B)
Headron, John A. (C)
Lant, Stewart G. (B)
McGrath, Terence (B)
Meyerhoff, Charles F. (C)
Meyerhoff, William (C)
Moore, Charles R. (C)
Moro, Remo J. (C)
Mucerino, Fred (B)
Nilsen, Ralph N. (C)
Ridella, A. J. (B)
Saari, Thomas A. (B)
Schanck, Harold C., Jr. (B)
Schilling, George J. (B)
Scordato, Vincent Frank (C)
Schmidt, Frederick E. (C)
Smathers, D. J. (B)
Spear, Warren M. (C)
Stendardi, Paul S. (B)

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Estes, Edward Richard, Jr. (B)

NIAGARA FRONTIER

Ameroso, Dominic (B)
Kolasa, Michael (B)

NORTH CENTRAL OHIO

Kiefer, John C. (C)
Lobdell, Vern A. (B)
Simms, Charles E. (C)
Young, Ralph O. (C)

NORTHERN NEW YORK

Bosworth, Orson (C)
Emmerich, Eugene W. (D)

NORTHWEST

Sperry, Joseph H. (B)

NORTHWESTERN PENNSYLVANIA

Lenz, Michael F. (C)

OKLAHOMA CITY

Stevens, David E. (C)

PEORIA

Williams, Allen James (C)

PHILADELPHIA

Oleair, Alex M. (C)
Schafer, H. W. (B)
Webster, Henry M. (C)
Wersler, Clarence F. (C)
Wismer, Samuel W., Jr. (B)

PITTSBURGH

Gulasy, Joseph (C)
Keat, W. George (C)

RICHMOND

Miller, William S. (C)
Robbins, J. R. (C)
Wiswall, James L. (C)

SAGINAW VALLEY

Duba, David E. (D)
Hofman, Eugene H. (D)

SAINT LOUIS

Jasper, Edward A. (B)

SALT LAKE CITY

Burton, John T. (B)
Watson, Alfred (B)

SANGAMON VALLEY

Seerest, D. F. (C)

SANTA CLARA VALLEY

Christensen, James O. (B)

SYRACUSE

Jacob, Carl E. (C)
Harders, Paul H. (C)

TUCSON

Nutt, Ashley A. (C)
Rautenstrauch, Robert (C)
Voorhies, Franklin E. (C)
Willis, Harold E. (B)

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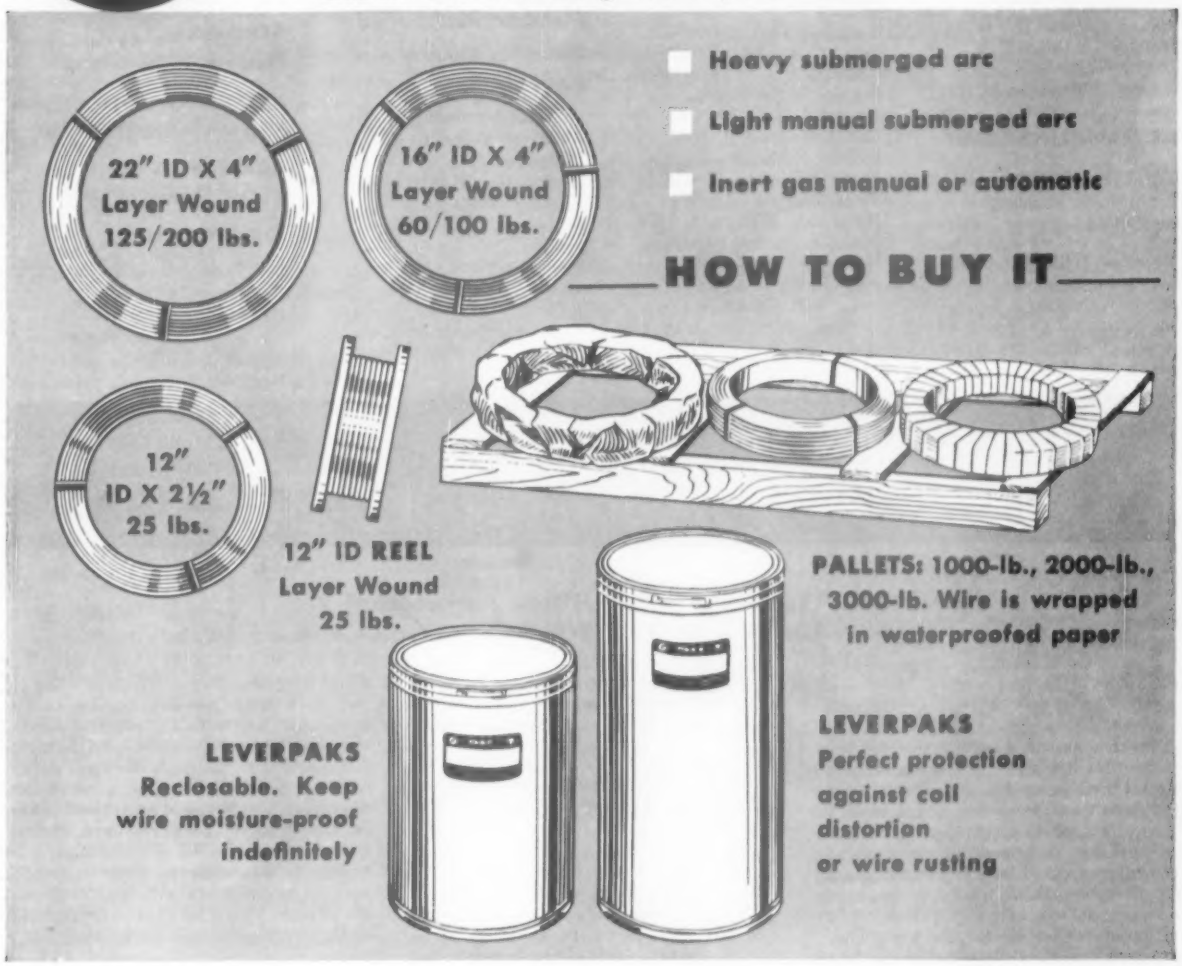
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Chappelear, Vernon C. (C)
Clayton, Herbert Arthur (C)
Cullers, William A. (C)
Davis, William T. (C)
Duty, James M. (C)
Goodin, Gordon M. (C)
Johnson, Elden G. (C)
Reid, Wilson C. (C)
Robinson, John W., Jr. (C)
Slaughter, William I. (B)
Smith, Wayne (C)
Stewart, Thomas H. (C)

WESTERN MICHIGAN

Martyniuk, Ernest T. (B)

WICHITA

Manewal, Willard G. (B)

YORK-CENTRAL PENNSYLVANIA

Duffield, J. Walter (C)
Hopper, Douglas A. (B)
Mentzer, Arnold D. (C)
Witmer, J. Kenneth (C)

NOT IN SECTIONS

Allen, J. O. (C)
Anderson, Carl A. (C)
Belk, Wilber (B)
Bondi, Manuel Charles (B)
Bridges, Willie R. (C)
Brown, J. H. (B)
Christ, Herman H. (B)
Delisle, Robert A. (B)
Dunn, Edwin A., Jr. (C)
Frost, Elmer F., Jr. (B)
Hagerman, William A. (B)
Jones, A. Darby (B)
Kaminis, Peter C. (B)
Lester, H. Grady, Jr. (B)
Lind, Willard M. (B)
McGillivray H. J. (B)
McKenzie, Dan, Jr. (C)
Meyer, William F., Jr. (B)
Paul, William B., Jr. (C)
Tropf, William J. (B)
Yoakley, P. R. (B)

Members Reclassified

During the Month of May

BOSTON

Johnson, Thure A. (C to B)
Mahoney, Cornelius D. (C to B)
Murphy, Harry J. (C to B)
Rogers, Robert B. (C to B)
Turck, Herbert (C to B)

BRIDGEPORT

Christie, John L. (B to A)

DETROIT

Kutchera, Richard E. (D to C)

LONG ISLAND

Berry, Keith W. (C to B)
Noble, Edward (C to B)

MILWAUKEE

Chyle, John J. (B to A)

NEBRASKA

Bernstein, Robert (C to B)

NEW YORK

Bellware, Morris D. (C to B)

NORTHWEST

Nielsen, Howard (B to A)

PITTSBURGH

Duffer, J. C. (C to B)

ABSTRACTS OF CURRENT PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,707,743—Welding Jig—Walter H. Jenkins, Goldsboro, N. C., assignor to Dewey Bros., Inc., Goldsboro, N. C.

Jenkins' patented welding jig includes a frame that has a plurality of rollers positioned thereon for defining a straight supporting surface for positioning a blank in the frame. Fluid-operated pistons are positioned for movement perpendicular to the supporting surface for engaging articles thereon. Other fluid-operated cylinders are positioned for motion transversely of the supporting surface and have clamping jaws operatively associated therewith for engaging a workpiece on the support surface, if desired.

2,707,821—Cold Pressure Welding—Anthony Bagnold Sowter, Middlesex, England, assignor to the General Electric Co. Ltd., London, England.

This patent is on cold-pressure spot lap welding of two members of ductile metal. The method comprises cleaning the areas of contact to be joined and arranging the members with the cleaned areas in contacting relation. One of the contacting members is supported against surface distortion and a pressure is applied in a direction at right angles to the interface between the members to cause an indentation in the second member coupled with the simultaneous drawing of the second member and indenting the first member and creating an extensive action at the interface to change the same from flat to rounded configuration. Such indentation and drawing is sufficient in its action on the members to cause an interfacial metal flow and extensive action as to create a solid phase welding bond at such interface.

2,707,822—Method for Cold Pressure Welding—Anthony Bagnold Sowter, Wembley, England, assignor to the General Electric Co. Ltd., London, England.

This patent relates to the joining of a pair of rodlike members of cold pressure weldable material and comprises flattening the end portions of the members to be joined, cleaning faces of the flattened end portions and placing them in superimposed relation. Pressure is applied over an oblong rectangular area of the superposed end portions and extending to points relatively close to short edges of such end portions to cause a metal flow and pressure weld as in Patent No. 2,707,821.

2,707,823—Method of Making Wire Joints by Cold Pressure Welding—Anthony Bagnold Sowter, Wembley, England, assignor to the General Electric Co. Ltd., London, England.

This patent to Sowter relates to a method of joining a pair of members of substantially circular cross section by cold pressure welding technique. First the members are arranged with the portions to be joined in overlapping, aligned relation to engage one another at a substantially linear interface. The outer halves of each member are supported against distortion while allowing the metal of the unsupported inner and adjacent halves of each member to cold flow freely under the effect of welding pressure applied to the members. Pressure is applied to distort the metal of the inner halves and the metal flow starts at and adjacent to the interface and changes the same from a linear configuration to an extended lateral area. Pressure application is continued until substantially the entire metal of the unsupported halves of the members flows outwardly and the members are combined into a single member by a solid phase welding bond at the interfacial metal flow point.

2,707,824—Method of Making Cold-Weld Joints—Anthony Bagnold Sowter, Wembley, England, assignor to the General Electric Co. Ltd., London, England.

This patent relates to a method of joining a wire and a plate member wherein the members to be joined are provided with uncontaminated metallic surfaces in contact with each other and wherein the outer half of the wire is supported against deformation. A localized area of the plate is subjected to a pressure in a direction substantially at right angles to the plate to effect an indention extending through the superposed plate and into the wire to distort the surrounding metal at the interface to change it from an initial substantially linear configuration into an extended lateral area. This creates an intensive interfacial metal flow to weld the wire and plate by a solid phase welding bond.

2,707,825—Method of Pressure Weld-

ING—Anthony Bagnold Sowter, Wembley, England, assignor to the General Electric Co. Ltd., London, England.

A method of joining a pair of plates to a circular in cross-section member is disclosed in this patent. Uncontaminated metallic surfaces are provided on the plates and the circular-section member with the circular-section member being placed between the pair of plates. Pressure is applied to opposed localized areas on the outer surfaces of the plates and in a direction at right angles thereto to effect indentations extending through the plates and into the circular-section member. This distorts the metal of such circular-section member at and near the interfacial areas to provide extended lateral areas and to create an intensive interfacial metal flow for solid phase welding action.

2,707,826—METHOD OF MAKING COLD WELDED WIRE JOINTS—Anthony Bagnold Sowter, Wembley, England, assignor to the General Electric Co. Ltd., London, England.

This further patent to Sowter relates to the joining of a pair of substantially circular cross-section members. The members are superimposed and pressure is applied to opposed circular welding areas of the contacting portions of the members in a direction substantially at right angles to a common tangential plane of the contacting members to effect indentations of the members and the desired solid phase welding action.

2,708,129—ARC WELDING STUD—Frank K. Kelemen, Haddonfield, and Rex A. Taylor, Moorestown, N. J., assignors to KSM Products, Inc., Merchantville, N. J.

The patented stud comprises a stud proper having a burn-off length and a portion adjacent the burn-off length which remains solid during the weld cycle and forms the base of the weld. A solid, self-sustaining, cohesive flux charge is mounted in a weld end portion of the stud. The burn-off length has a mass-diminishing indentation provided therein.

2,708,228—APPARATUS FOR THE AUTOMATIC PRODUCTION OF ENDLESS LOOP OF WIRE FROM WIRE STOCK—John Douglas Crabbe, Liverpool, and Eric Holroyd, Speke, Liverpool, England, assignors to Dunlop Tire and Rubber Corp., Erie County, N. Y.

This patented apparatus includes loop forming mechanism and a pair of welding machines, one on each side of the loop forming mechanism. Each welding machine has a pair of gripping electrodes for holding the ends of a loop in position for welding action, and a transfer means is provided having a pair of loop-carrying elements, one between the loop forming mechanism and each one of the welding machines. These transfer means are movable alternately between the loop-forming mechanism and its respective welding machine. Common drive means are provided for severing the formed loops and moving the transfer means at proper intervals in operation of the loop-forming mechanism.

2,708,229—ELECTRODE HOLDERS FOR ARC WELDING—Ian Jack Pickering, Great Barr, Birmingham, England, assignor to the General Electric Co. Ltd., London, England.

The patented electrode holder is for use with two-phase welding current systems and the holder comprises two arms electrically insulated from each other with one arm having adjacent its extremity a surface for engaging one electrode of a double electrode. The other arm provides a fulcrum for a lever having a surface adapter to engage the other electrode of the double electrode. The electrode positioned by the first arm is angularly adjustable relative in the second arm to vary the angle of position of the double electrode.

2,708,641—METHOD OF APPLYING METAL COATINGS TO VALVES—Arthur T. Cape, Los Angeles, Calif., assignor to Coast Metals, Inc., Little Ferry, N. J.

Cape's patent is on a method of providing a wearing surface for valves and similar articles, which surface is described as a welded-on facing of a protective metal. The method comprises supporting the valve so that an annular receiving surface thereon is facing in an upward direction, and is supported at an acute angle with the horizontal. The surface is rotated about its own axis at a uniform speed. This surface is locally heated until substantially molten and a measured quantity of molten surfacing metal is rapidly and uniformly poured from one point on to the rotating surface. The temperature of the molten material and the temperature of the substantially molten rotating surface cause instantaneous coating of the molten surface with the facing material which bonds to such surface.

2,708,702—LAMP BASE WELDING—Warren F. Albrecht, Euclid, Ohio, assignor to General Electric Co., a corporation of New York.

This patent relates to the welding of a lead-in wire to a metal part of the base of an electric lamp and includes the step of making a preliminary low resistance contact connection between a short lead wire and the metal part. The end of the stud is connected to an electrode and a current having a drooping characteristic is momentarily passed through the metal part and the stub with the electrode being negative in polarity. The electrode is maintained for the duration of the welding operation substantially in the position to which it was brought at the time of contact with the end of the stub so as to first form a molten bead on the end of the stub and simultaneously form an arc which continues to fuse the stub and cause it to draw back until it fuses to the metal part of the base.

2,708,786—MANUFACTURE OF CYCLE FRAMES—Tom Watson, Birmingham, England, assignor to Walton and Brown Ltd., Birmingham, England, a company of Great Britain.

This patent relates to a method of making cycle frame components consisting of pressing two blanks so that they each comprise a main channel and a pair of branch channels extending in opposite directions from the main channel. These two pressings are secured together in edge to edge relation by a welding operation and with the concave faces of the pressings facing toward each other to provide a main tubular part and two branch tubes extending therefrom. The main tubular part is divided longitudinally to provide two separate units each comprising a branch tube and an integral part tubular portion, which units are thereafter further processed in making cycle frames therefrom.

2,709,212—WELDING TIP HOLDER—John Macewka, Detroit, Mich.

The patented electrode holder comprises a body having a central bore extending therethrough and a bearing for holding a welding electrode in position is seated adjacent one end of the body in the bore. A longitudinally movable spool is disposed in the bore and it has a portion protruding into a transverse opening extending through the body. The parts are arranged so that movement of a tapered object through the transverse opening will move the spool away from such opening and change the relationship of the spool to the bearing to loosen an electrode disposed in the bearing.

2,709,213—METHOD OF HARDSURFACING—Glenn J. Gibson, Berkeley Heights, N. J., assignor to Air Reduction Co., Inc., New York, N. J.

This patent relates to a method of hard facing a metallic workpiece and it comprises establishing an arc between an electrode and a workpiece to form a pool of molten metal on the workpiece and this arc is moved over the workpiece. Particles of a refractory material are introduced behind the arc into the pool of molten metal produced by the arc on the workpiece.

Mark Your Calendar, NOW, for

OCTOBER 17–21, 1955

AWS NATIONAL FALL MEETING

Bellevue-Stratford Hotel, Philadelphia, Pa.

NEWS of The Industry

New Victor Branch

On June 1, 1955, Victor Equipment Co. opened a new branch office in Stockton, Calif., 1100 E. Main St. This new store is completely stocked and equipped to service the Stockton area on welding and cutting equipment and supplies, gas or electric, and with complete repair facilities.

Richard Labagh, current Branch Manager of Victor's Sacramento branch, has been named District Manager of the Sacramento-Stockton areas. Neal Holmes, Victor Field Service Engineer, with headquarters in Stockton has been named Branch Manager of the new Stockton store.

NCG Elects New Officers

Charles J. Haines, president, National Cylinder Gas Co., has announced that, at a recent meeting of the Board of Directors, Walter H. Girdler, Jr., a director, was elected a vice-president of the company and Harold W. Alenduff, treasurer.

Mr. Girdler was a vice-president of the Girdler Corp., which by merger with National Cylinder Gas Co. in 1953 became the Girdler Co., a division of National Cylinder. He joined the Girdler Corp. in 1937 and was elected a director in 1945.

Mr. Alenduff, a certified public accountant, joined National Cylinder Gas Co. in 1936 and was elected assistant treasurer in 1942.

New Appointments Made by Metal & Thermit

Two new appointments have been announced by the Metal & Thermit Corp., producers of metals, industrial chemicals, welding equipment and supplies. According to H. E. Martin, president, J. E. Stareck has been made director of research and H. D. McLeese general sales manager.

In his new post, Dr. Stareck will also continue to direct the research activities of United Chromium, Inc., a subsidiary of Metal & Thermit. He joined the research staff of United Chromium, Inc., in 1935 and for a number of years was associated with its Waterbury, Conn., laboratories. In 1941 he moved to United Chromium's Detroit research laboratories as Director of Research.

Jesse Stareck was born in Petersburg, Mich., on Mar. 17, 1905. He was graduated from the University of Kansas in 1927 and later from its Graduate School, receiving his M.A. in 1930 and his Ph.D. in Chemistry in 1934.

Mr. McLeese, previously vice-president and general sales manager of United Chromium, Inc., will direct the sales of all Metal & Thermit and United Chromium products, making his headquarters in the company's executive offices in New York.

Mr. McLeese was graduated from the University of Michigan with a degree in Chemical Engineering, and obtained his Master's degree at Columbia University.

Hill Equipment Moves to New Building

The Hill Equipment Engineering Co., formerly located at 4135 Gratiot St., St. Louis, Mo., has moved into its new building at 1413 Pennsylvania Ave., "Pagedale," St. Louis 14, Mo. The new quarters, a modern red brick building of 8000 sq ft, are approximately 25% larger than the previous one, and are equipped with two overhead loading doors, one equipped with a two-ton electric hoist to serve pick-up trucks.

Convenient off-street parking space is provided for private cars and trucks. The office and show room are air-conditioned.

The Hill Equipment Engineering Co., organized in November 1929 by Lockwood Hill, specializes in arc-welding equipment and supplies. Their territory is Metropolitan St. Louis, Eastern Missouri and Illinois from the southern border up to, and including, Peoria.

The personnel of this organization presently consists of 18 members. Mr. Hill is president; V. V. Netch and S. G. Hill, vice-presidents; George A. Bland, secretary and sales manager; D. J. Buchanan, treasurer; O. A. Schmidt, assistant to treasurer; and A. J. Rieger, director.

In 1930, this firm pioneered in the formation of the St. Louis Welding Society, the group which later became the nucleus of the St. Louis Section of the American Welding Society.

Caluwaert Elected NWSA President

E. C. Caluwaert, OKI Welding Supply Co., 1630 Walnut St., Cincinnati 10, Ohio, was elected president of the National Welding Supply Assn. at the Association's Eleventh Annual Convention at the Edgewater Beach Hotel, Chicago, last week.

Mr. Caluwaert is a charter member of the association, has been a director for many years, and for the past year has served as vice-president representing the association's central zone. This zone includes the states of Michigan, Illinois, Indiana, Iowa, Ohio and Wisconsin.

In addition, Mr. Caluwaert has been active in committee work, having chairmanned the important Convention Committee.

The Convention Committee arranged this year's meeting in Chicago, which was held May 18th, 19th and 20th. This was the largest convention yet held, being attended by more than 600 distributors and manufacturers of welding supplies and equipment. The addresses presented by the speakers at these business sessions were enthusiastically received. The President's Reception on the opening evening of the convention and the Associate Members' Reception on the evening of May 18th were both well attended and thoroughly enjoyed by the delegates.

E. C. Caluwaert

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Organized on Sept. 17, 1945, the association has experienced a rapid increase in membership until it now is composed of over 400 of the leading distributors and manufacturers of welding supplies and equipment throughout the country. The objectives of the association are to promote and maintain constructive cooperation among welding equipment and supply distributors and their sources of supply in order to advance their mutual interests; inspire the observance of high business methods to make for efficient and profitable operation and encourage adherence to sound policies and practices; all to the end that the welding supply distributors may retain their place and identity as an essential and efficient service in the distribution of welding equipment, supplies and gases.

Reid-Avery Appoints Neville

Marshall E. Reid, chairman of the board of the Reid-Avery Co., announces the appointment of Philip J. Neville as treasurer and director of that company. He will succeed John G. Sutton, treasurer since 1943, who has asked to be relieved of his duties.

Born in Baltimore, Mr. Neville attended the Baltimore Polytechnic Institute and the Johns Hopkins University. He is a certified public accountant of Maryland, and was recently associated with the firm of Peat, Marwick, Mitchell & Co., certified public accountants, as resident manager of their Baltimore office. Mr. Neville is a member of the American Institute of Accountants and the Maryland Association of Certified Public Accountants

At the same time, Mr. Reed announces the resignation of L. H. Christensen as executive vice-president and secretary of the Reid-Avery Co., Inc., as of May 31, 1955.

Mr. Christensen has been with the Reid-Avery Co. in various capacities since 1929, and will remain with the organization as a consultant.

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New K-G Distributors

The K-G Equipment Co., Inc., Allentown, Pa., manufacturers of precision welding and cutting equipment for industry and oxygen therapy equipment for the medical profession, announce the appointment of the following distributors for their industrial equipment: Air Products of Texas, 1615 Chenevert St., Houston, Tex; Alabama Oxygen Co., 2028 Vanderbilt Rd., Birmingham, Ala.; Billen Supply Co., 1102 N. Colony Rd., Meriden, Conn.; Clements Welding & Machine Co., 700 Hawk Ave., St. Louis, Mo.; and D & R Welding Supply, 736 E. Division St., Decatur, Ill.

Metal & Thermit to Erect New Building

Metal & Thermit Corp. has announced that it will erect a new general office building at Woodbridge, N. J., adjacent to the company's Woodbridge Research Laboratory. The firm now occupies offices at 100 E. 42nd St., New York City. The company's executive offices will remain in New York City.

Reportedly, the dual move results from expansion of activities and personnel and is designed to provide more efficient office facilities and to allow for future expansion of office needs.

The new building at Woodbridge, which is expected to be ready for occupancy by April 1956, will house the operating departments of Metal & Thermit Corp. and its subsidiary and affiliated companies in the New York metropolitan area, including sales headquarters for the northeastern region.

Executive offices in New York will continue to provide quarters for senior officers, production executives, division sales managers and the New York District sales staff, as well as certain advisory personnel.

National Electric Promotes Anderson

National Electric Welding Machines Co., of Bay City, Mich., designers and builders of welding machines since 1933 have announced the appointment of Richard V. Anderson as district sales manager with offices in the Maccabees Bldg. in Detroit. Associated with Mr. Anderson as sales engineers will be Gerald S. Ellsworth and Elton W. Turner.

Richard V. Anderson

Mr. Anderson has been associated with National since 1945 and has been active in machinery sales in Michigan since 1937. He was graduated from Rensselaer Polytechnic Institute, and is a member of the AMERICAN WELDING SOCIETY, the Engineering Society of Detroit and the American Institute of Electrical Engineers.

Mr. Ellsworth, also a graduate of RPI, was formerly with Union Carbide and Carbon Corp. and has been active in Michigan sales for the past five years.

Mr. Turner was graduated from Lehigh University with a B.S. in Mechanical Engineering. He was formerly with Ingersoll-Rand Corp. and later assistant sales manager for Hydraulic Power Division of the Hydraulic Press Manufacturing Co. in Mt. Gilead, Ohio.

Puritan's New Welding Supply

The Puritan Compressed Gas Corp. is erecting a modern, up-to-the-minute welding supply store at the southeast corner of 20th and Walnut St., Kansas City, Mo.

This new air-conditioned building will have a total of 7600 sq ft in which will be incorporated sales offices, display rooms, complete line of new welding supplies and equipment, and truck docks. The new addition to the Industrial Division of the company is being built for the purpose of making it

possible for customers to pick up all their requirements, welding supplies and gases at one location.

This company was the first oxygen manufacturer in Kansas City. It is operated by local men who pioneered the manufacturing and distribution of gases for welding and cutting in the Midwest. The principal officers are Parker B. Francis, president; Lowell R. Johnson, executive vice-president and general manager; John B. Francis, vice-president and treasurer; Parker B. Francis III, vice-president and secretary. Lee Page is general manager of the Industrial Division which will occupy this new building about September 1st.

Other facilities of the Puritan Corp. in Kansas City include a medical gas-producing plant in North Kansas City at 14th and Burlington, and an industrial oxygen plant at 13th and Eastern.

The general offices are located at 2008-14 Grand Ave.

New Sales Manager Appointed at Magnaflux

It has been announced that Roy O. Schiebel has been made sales manager of the Chicago nondestructive testing firm, Magnaflux Corp. by the firm's executive vice-president, W. E. Thomas. Mr. Schiebel brings 15 years of sales and management experience with Magnaflux Corp. to his new job as the firm's top sales executive.

After two years as a field engineer in the home office, Roy Schiebel was made Los Angeles branch manager in 1942. After the War, in 1945, Mr. Schiebel returned to Chicago as Midwest district

Roy O. Schiebel

manager, and in 1952 Magnaflux Corp. asked him to move again—to New York as Eastern district and export manager. Mr. Schiebel's return to Chicago as the new sales manager was announced by Magnaflux Corp. simultaneously with the resignation of Lloyd J. Oye who has taken the position of National Director of Marketing with Rezolin, Inc., of Los Angeles.

Mr. Schiebel is an active member of the AMERICAN WELDING SOCIETY and other organizations.

Magnaflux Corp. also announced that the new Eastern region manager would be Robert G. Strother who is moving from Western manager in Los Angeles. Kermit A. Skeie will move to Los Angeles as Western region manager from his present job as Chicago manager. The new manager of the Central Region in Chicago will be Denis P. Walsh who has been assistant to the vice-president. Mr. Skeie is a member of the AMERICAN WELDING SOCIETY.

Welding Research at B&W

During a press visitation held on May 17th at its Research Center in Alliance, Ohio, the Babcock and Wilcox Co. announced that welding equipment for a

HI-AMP

WELDING PRODUCTS

OUTSTANDING

By Comparison

Every Manufacturer "makes the best"-that's his natural conclusion, but after all, it's the Welder who uses the product that decides which really is the best. With HI-AMP Electrode Holders, as well as all other HI-AMP Welding Products, we urge you to check "every claim made" for superiority, because if you do we are confident you, too, will find HI-AMP Products are Outstanding by Comparison.

Sold only through Welding Supply Distributors in the U. S. and Canada.

WAGNER MFG. CO.
350 W. 1st SOUTH ST.
JACKSON, MISSOURI

Weld with Wagner

Aerial view of The Babcock & Wilcox Company's Research Center at Alliance, Ohio

new automatic submerged-arc process that will deposit metal up to five times as fast as comparable welding methods and at half the power cost is now in the final stages of development. Work is being conducted in the Welding Building.

The new process is being developed as a part of B&W's welding research program. In this field, emphasis has recently been placed on the welding of titanium, tungsten and zirconium, a technique essential to the fast-growing atomic energy industry; in the welding of dissimilar metals; and on perfecting of the new high-speed process. B&W's prime interest in developing this welding technique was to improve its fabricating techniques.

Known as the I^2RT method, the new process is applicable to submerged arc welding, in which the bare electrode is fed through a layer of granular flux, and to inert-gas-shielded welding. Standard submerged-arc welding practices have been based on the principle that deposit rate is directly proportional to the diameter of the electrode.

Cross section of welded butt joint employing I^2RT submerged arc welding process developed by B & W. Joint is in a three inch thick SA-212 steel plate at a deposit rate of 180 pounds per arc hour

This theory holds true with flux-coated electrodes, where current density is limited. However, B&W found that desired weld patterns could be made at deposit rates that were inversely proportional to wire size for a given current. In one case, for example, a higher deposit rate was obtained with a $^3/_{32}$-in. diam electrode at 650 amp than with a $^1/_8$-in. electrode at 800 amp.

Experiments subsequently revealed that the deposit rate at high current density is directly proportional to the length of the electrode wire from the contact shoe to the arc.

This discovery led to the I^2RT principle of submerged arc welding. The new process preheats the electrode almost to its melting point before it enters the arc. Thus the arc does not have to supply the sensible heat required to bring the metal to the melting point, as it does in standard submerged-arc processes. Practically all the energy absorbed by the electrode at the arc supplies heat of fusion to melt the metal.

Energy required to heat the electrode to the melting point is measured in terms of the square of the current (I^2), the resistance (R) of the electrode wire projecting from contact nozzle to arc and the time (T) that the current flows through any given cross section of the wire.

New welding metals for use in the atomic field are also being investigated, and the design of welding equipment is constantly undergoing improvement. Metal-joining equipment on hand includes submerged-arc automatic machines, atomic hydrogen, inert gas-protected metallic arc, as well as carbon arc and oxy-acetylene cutting and welding units. Radiographic inspection is being used to determine soundness of welds. For welds less than 2 in. thick, a 250-kw X-ray machine is used, and for heavier sections, the radioactive isotope Cobalt 60. Other tests are performed by fluorescent penetrant, magnetic powder and ultrasonic equipment. A wire drawing bench is being used to develop unusual alloy electrodes.

New Hobart Representative

Hobart Brothers Co., Troy, Ohio, has recently appointed Robert E. Roediger as district representative for territorial development in Alabama, Mississippi, Arkansas and Louisiana. Mr. Roediger will have supervision over cooperative distributor operations in sales of Hobart arc-welding equipment, supplies and electrodes—and will maintain his headquarters in Birmingham where complete sales and service facilities are available for Hobart Equipment. Mr. Roediger has been associated in sales work for the company since 1953.

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CORPORATION
QUALITY CONTROLLED
STAINLESS STEEL
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- Welds 200 inches per minute.
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- Designed for jobs where moving of parts is undesirable.
- Welding heads have insulated metal bearings for load carrying purposes and accurate wheel alignment.
- Current carried to rotary shafts by silver alloy contact brushes.
- Shaft and wheel assembly cooled internally by circulating water.
- Adjustable speed, reversible air motor drive unit. Regulator controls variable speed.
- Two separate air valves with lubricators, regulators and filter assemblies.
- Two separate starting buttons permit independent operation of wheels, open and closed and motor drive, off and on.
- Special sequence control permits separate operation of each function, yet controls are interlocked to permit instantaneous drop-out of all circuits.
- Equipped with Easy Flex Cables.

PROGRESSIVE *Welder Sales Company*

915 Oakland Avenue • Pontiac, Michigan

PERSONNEL

Davis Receives Award

A. F. Davis, vice-president and secretary of the Lincoln Electric Co., Cleveland, Ohio, was among the first recipients of a new award established by the Ohio State University to pay its highest tribute to its outstanding engineering alumni. The first "Distinguished Alumnus" awards were made by the university before 800 persons attending the Second Annual Engineering Conference for Engineers and Architects held in Columbus on May 6th.

Mr. Davis, selected by vote of the college faculty to receive the award, was cited for his "outstanding attainments as an industrial executive, sales and advertising genius, civic leader and a graduate engineer who fulfills his responsibility to education to the highest degree." Mr. Davis received a degree of M.E. in E.E. in 1914 at the Ohio State University and joined the Lincoln Electric Co. following his graduation. He is now senior vice-president and, in addition, secretary of the James F. Lincoln Arc Welding Foundation.

Owens Exhibits Paintings

According to a story published in a recent issue of the Beloit (Wis.) *Daily News*, James W. Owens, one of the pioneers of the welding field, has been very successful in experimenting with the use of rubber base paint as an art medium and has discovered in it an enjoyable and limitless hobby. This interest has resulted in four wall murals and a painting which has been exhibited in a Wisconsin Power and Light Co. window.

Mr. Owens is retired and lives at 703 Milwaukee Rd., Beloit. While painting his apartment some twenty months ago, he first saw the possibilities of this product as an art medium. He proceeded to paint a yacht racing scene in one of his rooms and this spurred him on to further efforts. Climax of his work to date has been the colorful painting "Peace or Annihilation." It is a dramatic presentation of the crucifix floating over the Pacific Ocean detonation of the atom bomb.

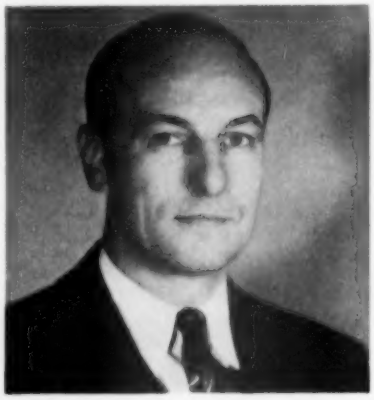
Mr. Owens is well known to the welding fraternity. In 1928, the American Society of Mechanical Engineers awarded him first prize of $10,000 in an international contest sponsored by the Lincoln Electric Co.

In 1929, he was awarded the Miller Memorial Medal by the AMERICAN WELDING SOCIETY, which he helped to organize. At one time he served as AWS vice-president and in 1952 he was made an honorary member.

Mr. Owens also has been welding aid for the Navy, director of welding and research for the Newport News Shipyard, and director of welding and technical assistant to the general manager, Beloit works of Fairbanks, Morse & Co.

Lytle Appointed Vice-President

The appointment of Arthur R. Lytle as vice-president in charge of Research for Electro Metallurgical Co., a Division of Union Carbide and Carbon Corp., was announced by A. L. Foscue, president of Electro Metallurgical.



Arthur R. Lytle

Mr. Lytle has been associated with the corporation since 1923 when he joined the Union Carbide and Carbon Research Laboratories at Niagara Falls, N. Y. In 1946, he became head of the Welding Department there and was subsequently appointed assistant manager of Research. In 1952 he moved to the New York office to occupy the post of Director of Research for Electro Metallurgical.

For the last two years of his connection with the Union Carbide laboratories, Mr. Lytle was responsible for all the metallurgical research activities there. Before then, he carried out and directed extensive research on the welding of metals. He developed many new welding rod compositions, including the first nonfuming bronze. Mr. Lytle also pioneered in the field of automatic welding machines, and was responsible for many advances in the use of the oxy-acetylene flame for hardening, powder-cutting and pressure-welding processes.

Mr. Lytle was born in Troy, N. Y., and was graduated from Rensselaer Polytechnic Institute as a Chemical Engineer in 1923. He is a member of the AMERICAN WELDING SOCIETY, American Society for Metals, and American Institute of Mining and Metallurgical Engineers.

Cook Joins Esso Research

Harry C. Cook, formerly associated with the Air Reduction Sales Co., has recently joined the staff of Esso Research & Engineering Co. in New York City.

Mr. Cook's new position is that of assistant to the Pipe Line Research Director. Their job is to coordinate the research work pertaining to pipe lines which is being carried on at the various subsidiaries and affiliates of Standard Oil Co. (New Jersey).

Mr. Cook is a member of the AMERICAN WELDING SOCIETY.

Oehler Named Manager

Irving A. Oehler has been named manager of manufacturing, in complete supervision of all manufacturing processes and related services, of the American Welding and Manufacturing Co., Warren, Ohio, William J. Sampson, Jr., president, announced recently.

Dr. Oehler has been administrative assistant to the president. He joined American Welding in 1942 as director of research and metallurgy. In 1952, he was appointed administrative assistant to the executive vice-president, and in January 1955 he was named administrative assistant to the president.

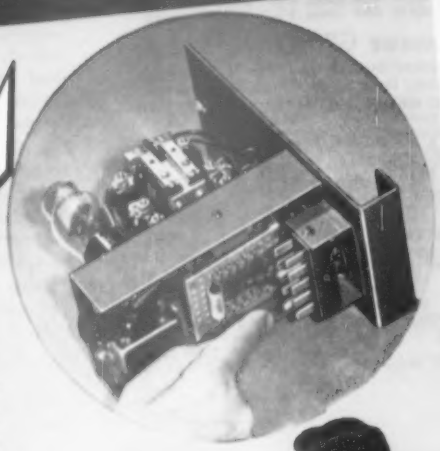
Before joining American Welding, Dr. Oehler was assistant chief metallurgist at Republic Steel Corp.'s Buffalo district. He received his electrical engineering degree from Rensselaer Polytechnic Institute in 1932, his master electrical engineering degree from the same institute in 1933 and his doctorate degree while studying on a RPI fellowship.

Nationally known for his work in welding, Dr. Oehler was recently appointed a member of the Titanium Welding Panel of the Metallurgical Advisory Committee on Titanium for the Ordnance Department. He is on the Resistance Welding Committee of the Welding Research Council. He is also a member of the Resistance Welding

for Better Welding Production...

INDUSTRIAL *Plug-In* UNITS!

Welding Press Control illustrating simple removal of plug-in electronic timer



Plug-In TIMERS

are designed to stand up under hard industrial usage. Both timers and sequencing relays can be installed in a matter of seconds. Down time is reduced to absolute minimum during replacement. Timing circuits are fail-safe—if any tube fails to fire, circuit will be opened and welding process stopped instantly.

Plug-in relays being removed from welding press controller Faster electrical maintenance

Plug-In RELAYS

are of special rugged industrial design and construction. Flexibility provided by plug-in feature (on both sequencing relays and timers), permits easy circuit changes without complete controller redesign.

Write for Bulletin 8991

Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin

SQUARE D COMPANY

GRAND
WELDERS' GROUND CLAMPS
• EXTRA STRONG
• FAST ACTION
• POSITIVE CONTACT
• HOLDS ANY SURFACE
• SPATTER PROOFED
QLW
QLW SERIES
Grand quick setting Ground Clamps of NACO No. 6 Super Steel are first choice with welders. Available in 3 popular sizes.
2-QLW 200 Amps 1¾" Max. Opening
4-QLW 400 Amps 3⅛" Max. Opening
6-QLW 600 Amps 5⅛" Max. Opening
Famous GRAND "C" Clamps
Alloy Steel (Stronger than forged) Spatter-Proofed Screws, Deep Throat – Replaceable Swivels
LIGHT SERVICE SERIES
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L SERIES
8 SIZES
2" TO 12"
ASM SERIES
7 SIZES
4" TO 18"
ASH SERIES
8 SIZES
¾" TO 12½"
Stocked and Distributed by
UNITED STATES STEEL SUPPLY CO.
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Committee of the American Welding Society.

Dr. Oehler is a member of the American Society for Metals, Society of Automotive Engineers, American Society for Testing Materials, American Association for the Advancement of Science, National Society of Professional Engineers, American Ordnance Association, Sigma XI, and past chairman of the Mahoning Valley Section of the American Welding Society. He is also a past chairman of the Warren Chapter, American Society for Metals.

Kinelski Joins Inco

Eugene H. Kinelski has joined the Development and Research Division of the International Nickel Co., Inc., as a research metallurgist in the Welding Section of the Research Laboratory at Bayonne, N. J., according to an announcement by Dr. W. A. Wesley, manager of the laboratory. The Welding Section is engaged in study of the welding of all types of alloys and in the development of new welding rods and coated electrodes.

Mr. Kinelski graduated from Purdue University in 1942 with the degree of Bachelor of Science in Metallurgical Engineering and afterward took up graduate study in metallurgy at Purdue and the University of Pittsburgh. Thereafter he was associated with several organizations before joining International Nickel.

Cotton Named to West Coast Post

The Burdett Oxygen Co., 3300 Lakeside Ave., Cleveland, Ohio, has announced the appointment of Charles Cotton as assistant sales manager of the West Coast plant. Before joining Burdett in 1947, Mr. Cotton amassed five years of welding experience and three years of sales experience in selling oxygen, acetylene and equipment. He is 33 years old, married and has two children.

Pomfret Promoted

R. A. Pomfret has been promoted to chief of development and research, Central Technical Department, of the Shipbuilding Division of Bethlehem Steel Co. according to an announcement made by Richard H. Tingey, technical manager. He succeeds Paul Ffield who was recently transferred to Bethlehem, Pa., as technical adviser on the staff of the operating vice-president.

Born in Waltham, Mass., Mr. Pomfret graduated from the Reading (Mass.) High School and later attended University of Alabama where he graduated in

R. A. Pomfret

1934 with a degree of B.S. in Metallurgical Engineering. He joined the Bethlehem organization in 1935 as Assistant Material Engineer and later became Materials Engineer, which position he held prior to taking over his new duties. He is a member of the American Welding Society, American Society of Metals and American Society for Testing Materials.

CHANGE OF RESIDENCE ADDRESS OR COMPANY AFFILIATION

Date .....

(Please Print)

Name ..... , ...
LAST FIRST MIDDLE

Residence Address .....
STREET

.....
CITY ZONE STATE

Company Name and Address .....
COMPANY NAME

.....
STREET

.....
CITY ZONE STATE

Title of position held .....

Mail should be sent to my residence ☐ company ☐ (check one)

Note: To assure that your copy of the Welding Journal is mailed to your new address, this change of address notice must be received at American Welding Society, 33 West 39th Street, New York 18, N. Y. no later than the 25th of the month previous to issue mailing.

Morse Honored by Burdette

E. J. "Gene" Morse, vice-president in charge of sales at the Burdette Oxygen Co., Cleveland, Ohio, was honored by his associates with a surprise testimonial dinner at the Lakeshore Hotel to com-

memorate his 30th year with the company. Also honored at the dinner was Mrs. Rose Gallagher who is celebrating her 32nd year with the company. Mr. Morse was given a complete set of golf clubs and a golf bag by the company and a sterling silver cigarette box by his associates. Mrs. Gallagher was given a lovely wrist watch by the company.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-666. Sales Engineer. Age 28. Married. Veteran. Six years' practical experience in welding and fabricating. Two years' experience in sales and service with flame-cutting equipment, oxy-acetylene and arc welding, inert arc welding and inert arc spot welding equipment. Capable of recommending proper procedures and techniques with above equipment. Desire similar position in sales engineering. Will relocate. Prefer middle west.

A-673. Interested in supervisor or sales. Sixteen years' experience in all phases of welding. Full knowledge of heavy and light-pressure vessel welding, structural assemblies, a-c, d-c single and tandem submerged-arc welding. Familiar with all types of electrodes, mild steel, hard facing, low-hydrogen, low-chrome alloys and stainless steel. Experience covers supervision, engineering, technician, instruction and testing. Have prepared joint designs and welding procedures for production. Age 38, married. Will relocate. Résumé upon request.

A-674. Mature salesman open for position—high-calibre, practical man with proved sales record in welding equipment, welding machines and alloys, with a good following in Chicago area. Any inquiries will be promptly answered.

A-675. Welding Engineer. 26 years of age. Will obtain M.S. in August 1955. 3 years' experience in welding development including studies of high temperature alloys, stainless steels, titanium and intensive investigations on the weldability of armor steels. Seeks position as welding metallurgist. Available September. All replies acknowledged.

•

Positions Vacant

Consultant Metallurgist—$8360 per annum—candidates should have broad experience in welding metallurgy and laboratory test procedures.

Welding Engineer—$5940 per annum—with metallurgical background in the development of welding procedures.

Applicants should forward Application for Federal Employment, Standard Form 57, which is obtainable in Post Offices or any government installation, directly to the Industrial Relations Officer, U. S. Naval Engineering Experiment Station, Annapolis, Md.

BECKER

KEEN-ARC CARBONS

FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

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OPPORTUNITY

Leading manufacturer of resistance welding machines and automatic equipment has opening for qualified men.

ASSISTANT GENERAL MANAGER

to supervise production. Must have thorough knowledge of resistance welding manufacturing.

MACHINE DESIGNERS

Can make rapid advancement. Send resume. Replies held in strictest confidence. Box V-323

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INSPECTION and TESTING of Welding and Weldments

QUALIFICATION of Procedures and Operators

Main Laboratories . . . . . Hoboken, N. J.

Boston Providence Philadelphia Wilmington New York Chicago Los Angeles Memphis Dallas Denver

NEW PRODUCTS

Iron-Powder Electrodes

Especially designed for high-speed production welding of lap, fillet and flat-beveled joints, the new Sureweld iron-powder electrodes, according to National Cylinder Gas Co., cost less to use and provide up to 25% faster welding than E-6012 and E-6020 electrodes of the *next larger* size used at higher currents.

Two types of the new iron powder electrodes are available. Sureweld "24" (AWS type E-6024) is for horizontal fillets, lap and flat-beveled joints now welded with E-6012 electrodes. Sureweld "27" (AWS type E-6027) is for operations now welded with E-6020 electrodes. Both types work equally well with a-c or d-c current.

For complete information write to National Cylinder Gas Co., 840 N. Michigan Ave., Chicago 11, Ill.

Portable Welders

A new portable electric welder for light gage metals, "Hi-Amp Model 5403" has been placed on the market by the Sittler Corp. of Chicago.

Principal feature of the Model 5403 is its built-in "Electronic Thyrotron Timing Control and Solenoid Contactor." According to the manufacturer, the use of this precision-type timer provides welding accuracy from one-tenth of a second to a full second, effectively preventing any danger of burning through the work.

An unusually wide throat depth of 6 in. on the Model 5403 can be extended to 18 in. by the use of readily available extension arm accessories. The welder's opening is easily adjusted from 3 to 11½ in. Both transformer and welding arms

Sittler Hi-Amp Portable Welder Model 5403

are watercooled. Welder output is 3 amp for secondary open circuit voltage and over 20,000 amp for short circuit. While the welder weighs only 55 lb and can be moved about by hand, its carrying handle can be used with a sky hook; a floor stand is also available for foot operation.

Literature and other information on the "Hi-Amp" welder line may be obtained by writing direct to the Sittler Corp., 18 North Ada St., Chicago 7, Ill.

Regulators

Weldit, Inc., introduces their new "Duo-Trol," the new Weldit Series 50 Duo-Control Regulator for Oxygen and all Fuel Gas control.

Designed to meet the exacting requirements of modern industry, the Duo-Trol is precision built to take rough handling while giving the utmost in accurate regulation, according to the manufacturer. Compact in size, with forged body and bonnet, it is adapted for both light- and heavy-duty work.

For further information, contact Weldit, Inc., 990 Oakman Blvd., Detroit, Mich.

Vickers D-C Welder

The Controlarc, a new magnetic amplifier-rectifier d-c welder which is said to provide full time automatic arc control under all conditions, is now being produced by Vickers Electric Division, Vickers, Inc., St. Louis, a unit of the Sperry Corp.

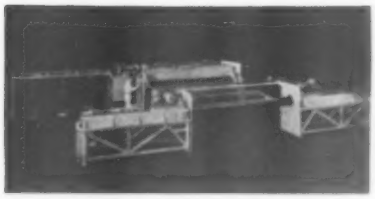
According to the manufacturer, Controlarc is available in 200-, 300- and 400-amp models, and automatically and continuously adjusts the selected arc characteristics to every change in welding condition, from arc strike to end of pass, assuring easy, clean arc strikes; hot starts and immediate penetration; uniform fusion and steady rate of metal deposit; prevention of arc "pop outs" and current drop-off during pass.

Complete information on the Vickers Controlarc magnetic amplifier rectifier d-c Welder is available from the manufacturer, Vickers Electric Division, 1815 Locust St., St. Louis 3, Mo.

Resistance Welder For Wire Mesh

A huge new mechanically operated high-speed resistance welding machine that produces wire mesh up to 13 ft wide from coiled steel wire in a continuous operation has been developed and built by Expert Welding Machine Division, 17144 Mt. Elliott Ave., Detroit 12, Mich.

The compactly designed machine and its accessories are about 7 ft high and



occupy a floor space about 35 by 32 ft. It will fabricate mesh from 4- to 14-gage wire at a rate of 60 cross wires per minute. Extreme operating flexibility is provided in the machine, which will handle up to 79 longitudinal wires with a wire spacing from 2-in. up. Cross wires can be spaced from 2 to 12 in. The machine will produce wire mesh in either square or rectangular patterns as desired.

Pencil Torch

A new Heliarc Pencil HW-9 torch is now available for inert-gas-shielded arc welding of light metals. The Pencil HW-9, with its 180-deg head is designed for working in tight places that are hard to reach with torches of standard head angle. This new Heliarc torch has been developed and introduced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St.,

New York 17, N. Y. Air-cooled and with 110-amp continuous-duty current capacity, the Pencil HW-9 will join mild steel and hard-to-weld metals like aluminum, magnesium, stainless steel, Monel, Everdur, copper, brass and high-alloy steels.

The Pencil HW-9 is exceptionally light and small for easy handling and manipulation. Without cable, the 7-in. torch weighs only 3 oz and has a maximum diameter of $^3/_4$ in. Yet, in spite of its compact size and high current capacity, the Pencil HW-9 is comfortable and safe to operate.

For complete information, contact Linde Air Products Co. at above address.

Automatic Welding Fixture

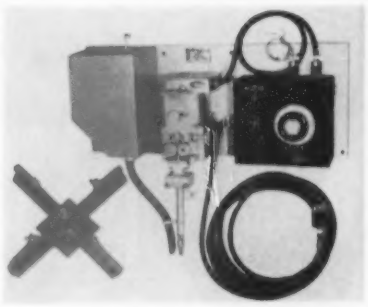
The Lewis Welding & Engineering Corp., 78 Interstate St. Bedford, Ohio, announces the development and availability of a new universal fixture designed to handle a wide variety of weldments. Exclusive features of this unit include full portability, simultaneous

three-directional travel, 360-deg boom rotation and an adjustable base. In addition, any standard head can be utilized with this fixture for automatic welding, flame cutting or hardening operations.

Complete details may be obtained by writing on company letterhead to Lewis Welding & Engineering Corp. at the above address.

Automatic Welding Head

Hobart Brothers Co., Troy, Ohio, is announcing a new automatic welding head designed especially for use with the new Hobart Constant Voltage "Powromatic" Welder.



Illustrated is the complete unit including simplified controls, wire feed and current pick-up assembly, flux hopper and wire reel. If a different arrangement is desired, any one or more of the components can easily be removed from the steel panel to set up the job at hand.

It has capacity for automatic welding with wire sizes 0.035 to $^1/_4$ in. inclusive. One set of wire feed rolls, size specified by customer, is standard equipment. Capacity of the flux hopper is 25 lb and the adjustable wire reel will handle coils 12 to 16 in. ID, $2^1/_2$ to 4 in. wide. The reel can be located at the most desirable point for the job at hand.

For further information, write Hobart Bros. Co., Troy, Ohio.

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AN AIR REDUCTION PRODUCT

FOR WELDING AND CUTTING...

IN THE RED DRUM

HIGHEST QUALITY

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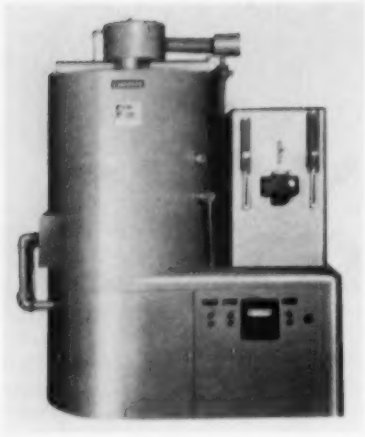
GENERAL OFFICES: 60 EAST 42ND STREET, NEW YORK 17, N. Y.

A DIVISION OF AIR REDUCTION COMPANY, INCORPORATED



Bright Brazing

A new streamlined endothermic atmosphere generator, completely wired, piped and assembled in a package unit is now offered by Lindberg Engineering Co., 2450 W. Hubbard St., Chicago 12, Ill. The Hyen Hydryzing generator is a fully automatic process for producing low-cost protective atmosphere for bright hardening, bright annealing, or bright brazing of steel totally free from decarburization or carburization. Available in 500, 750, and 1500 cfh sizes the unit provides production economies and gives better, more precise operation with ease of maintenance.

For additional information write directly to the company.

Welding Positioner

The new P&H WP-1 Welding Positioner, recently developed by the Welding Division of the Harnischfeger Corp., is now available.

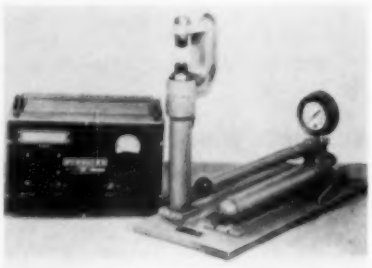
The WP-1 is designed for use as a bench model for faster production of smaller fabrications. With its 24-in. table in a horizontal position, it stands 15⅞ in. high. It weighs only 100 lb, and handles weldments up to 500 lb. A pedestal for floor mounting is also available as optional equipment.

Rotation of the WP-1's turntable can be done manually or with electric-motor drive. Also, the table tilts a full 135 deg from the horizontal without the weldment striking the positioner.

Further information about the new WP-1 Welding Positioner is available from the Welding Division, Harnischfeger Corp., Milwaukee 46, Wis., or from any of its district offices or welding distributors.

Surface Resistance Indicator

Sunshine Scientific Instrument, 1810 Grant Ave., Philadelphia 15, Pa., announces a portable instrument used to test for the effectiveness of any cleaning process used to prepare metal for resistance welding. It provides an accurate

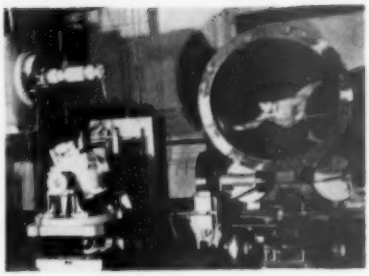


means for measuring the resistance between two pieces of metal in a matter of seconds. By knowing this resistance before welding, such common difficulties as electrode pickup, inconsistency of welds and metal expulsion can be greatly reduced. Designed for use with any resistance welding application, it is particularly valuable with aluminum welding.

The manufacturer has prepared a Catalog No. 12 describing this unit in detail. Catalog is available upon request to the company at the above address.

Isoscope

A new inspection tool which makes use of radioactive Cobalt 60 and is capable of radiographing—or "seeing through"—thickness of steel up to 7 in., has been developed by the Babcock & Wilcox Co. at their Barberton, Ohio, works, according to an announcement made recently. The unit has been christened the "Isoscope" a derivation of the words "isotope," a radioactive material, and "scope," for the power to see through metals. The "Isoscope" which has been under study and development by B&W for the past three years, requires only one-third the exposure time of a million volt X-ray unit, the announcement said, and paves the way for wider use of



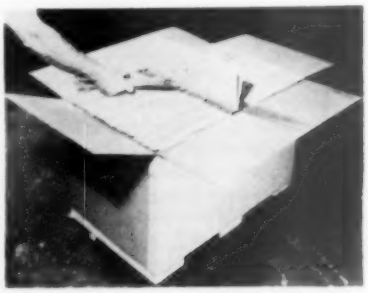
atomic energy in this industrial application.

The lead sphere of the "Isoscope" is encased in a steel jacket having a cylindrical rotor section built into it. By revolving the rotor 180 deg the radioactive source can be brought from the "safe" position to a point in line with the coned opening in the steel jacket allowing a beam of radiation to escape. This, in effect, results in a unit which can be turned "on" and "off," according to the announcement. In the accompanying photograph the unit is being used to radiograph the thick steel walls of a typical pressure vessel.

For further information, write to Babcock & Wilcox, 161 E. 42nd St., New York, N. Y.

Electrode Packaging

A. O. Smith Corp., Milwaukee, Wis., now ships a carload of A. O. Smith welding electrodes to larger users in just twenty 2000-lb corrugated Production-Paks made by Gaylord Container Corp. St. Louis, Mo. Formerly, eight hundred 50-lb boxes were used. Several benefits are claimed for



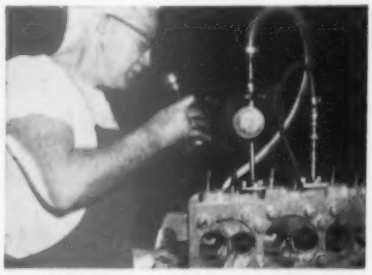
A. O. Smith customers for this type of packaging including: ease of handling in unloading, ease of storekeeping, ease of inventory control, ease of stacking, ease of distribution, and no complication of electrode brands.

These new A. O. Smith "Production-Paks" have a center divider and full overlap top. They are secured by three steel straps with metal protectors on the sides.

Uses Ni-Rod for machinability... Ni-Rod "55" for heavy sections

Cast iron "welding team" simplifies maintenance, cuts costs for Buffalo bus company.

1. Good build-up — Worn valve seat on an engine from one of the 720 busses operated by Niagara Frontier Transit System of Buffalo, N. Y., gets built up with Ni-Rod electrodes. Before being welded, the oil-impregnated casting was degassed in an oven for a half hour at 900°F. Then it was cooled, wire-brushed and preheated to 400°F.



2. Like new with Ni-Rod — Valve seat weld gets close inspection. Then the seat is re-machined. And finally it's pressure-tested. At this point, the men charged with maintenance of this huge bus fleet consider the valve head as good as new. They give a lot of the credit to *the soundness and machinability* of Ni-Rod welds. Mr. W. W. Kunz, who heads the maintenance department says, "Using Ni-Rod and Ni-Rod "55" for repairs on 75 to 100 busses every year gives us a very substantial saving."

3. Chalk one up for Ni-Rod "55", too — A crack that's dangerously close to the cylinder liner gets marked for repair with Ni-Rod's companion electrode, Ni-Rod "55". For stiff sections, like this engine block, and for heavier sections, high phosphorous irons, Ductile Iron, Ni-Resist® and high-strength cast irons, welders choose Ni-Rod "55". Like Ni-Rod, you can often use it *without preheat or postheat.*

If you work with cast iron, you can use this "welding team" profitably in your operation, too.

With Ni-Rod® and Ni-Rod "55"® you can, like this bus company, save worn or damaged cast iron parts that otherwise you'd scrap; and you can also simplify cast iron assembly work.

Ni-Rod and Ni-Rod "55" electrodes are easy to handle. And even welders of limited experience can produce *sound, machinable welds.*

Write today and ask for our FREE FOLDERS ON NI-ROD AND NI-ROD "55".

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street New York 5, N. Y.

INCO TRADE MARK **Welding Products**
Electrodes • Wires • Fluxes

Easyarc Electrode

The new Easyarc LH 7-16 electrode, recently announced by Air Reduction, is said to deposit over 60% more metal than conventional low-hydrogen electrodes, by actual test.

According to the manufacturer, the three factors making this welding speed possible are: (1) concentrated arc energy, (2) powdered iron coating melts and becomes part of the weld and (3) extra-heavy coating helps control arc action and allows higher currents to be used with complete safety.

For more information about the LH 7-16 and Airco's complete electrode line, send for "Pocket Guide to Electrodes" by writing to Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 60 E. 42nd St., New York 17, N. Y.

New Aluminum Alloy

Research is lifting the thermal barrier that has threatened the use of aluminum in supersonic aircraft of the future, it has been announced by Aluminum Company of America.

In lifting the veil on its new patented high-temperature aluminum alloy called X2219, Alcoa stated that other pending alloy developments will combine with the current one to effectively raise existing temperature limits on aluminum.

Use of aluminum in supersonic aircraft was jeopardized by elevated temperatures of high-speed flight. Friction with air at speeds over 1000 mph generated intense heat in the skin of an airplane. This heat, combined with that generated by the engine, threatened to raise the temperature in some parts beyond the efficient performance level of existing aluminum alloys.

Alcoa alloy X2219 is reported to offer excellent properties at 500 to 600° F and is now available in experimental quantities.

For additional information, write to Aluminum Company of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa.

Mobile Unit

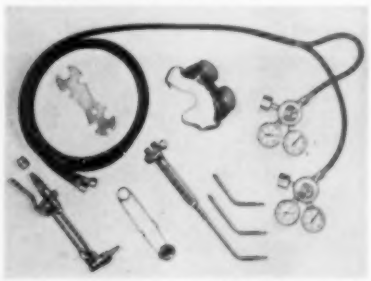
Moving a self-sufficient welding unit from one job to another may be accomplished with the speed of a pick-up truck with the jeep-powered mobile welder made by A. J. Parsons, Washington, Pa. The unit consists of a Lincoln 200- or 300-amp generator with a large built-in exciter generator mounted on a Willys 4-wheel drive jeep or truck.

One or three kilowatts at 115 v is supplied by the exciter generator to furnish lights on the job or run shop tools at the same time welding is being done. Power for the welder and generator is supplied by the truck engine by means of a belted power take-off system.

Aside from the power equipment, brackets for acetylene and oxygen tanks, plus boxes for storage of tools and equipment, are built into the units.

Welding and Cutting Outfit

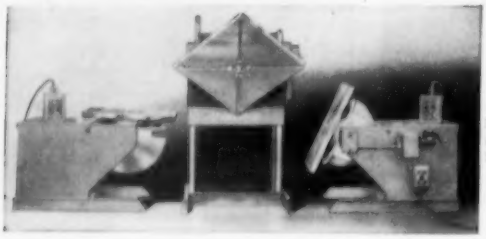
Dockson Corp., 3839 Wabash Ave., Detroit 8, Mich., announces a new, low-cost, high-quality outfit for welding, cutting, heating and brazing.



Described as being ideal for small plants, hobby work, home shops, farms, service stations, sheet metal plants, plumbers and heating contractors, this outfit will weld up to $^3/_{16}$ in. thickness and cut to $^1/_2$ in. thickness.

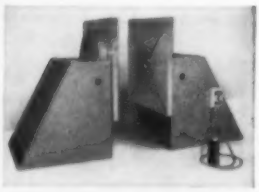
Complete information and your local distributor's name are available from Dockson Corp. at the above address.

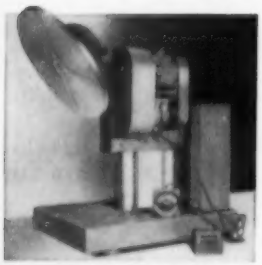
Steady, Positive, Precision Rotation for AUTOMATIC WELDING with *Aronson* Positioning Equipment.



UNIVERSAL Balanced POSITIONING
Model C 500 shown
25 lbs. to 2,000 lbs. capacity

HEAVY DUTY GEAR DRIVEN POSITIONING
Model HD 25 shown
500 lbs. to 24,000 lbs. capacity





HEAD and TAIL STOCK POSITIONING
Model HTS 5 shown
Capacities 5,000 lbs. to 160,000 lbs.

MODEL 21 (shown) SUPER GEAR DRIVEN POSITIONER with powered rotation tilt and elevation.

MODEL X-21 Powered rotation, ball bearing manual tilt and elevation.

MODEL 21-P Powered rotation and tilt, ball bearing manual elevation.

MODEL 21-E Powered rotation and elevation, ball bearing manual tilt.

MODEL X-21-PE Powered rotation, tilt and elevation. 5000 lbs. capacity @ 6" CG location.

Aronson TRACTRED Turning Rolls
Steady, positive, precision rotation for automatic welding. MODEL T1 (shown) capacity 6,000 lbs. per unit. MODEL T2 capacity 12,000 lbs. per unit. MODEL T3 capacity 18,000 lbs. per unit.

HEAVY DUTY PRECISION BUILT RUBBER TIRED TURNING ROLLS
5,000 lbs. to 150 tons capacity

Aronson MACHINE COMPANY
ARCADE, NEW YORK

FULL-TIME, AUTOMATIC ARC CONTROL

with the NEW VICKERS® Controlarc MAGNETIC AMPLIFIER-RECTIFIER DC Welder

- Easy, clean arc strikes
- Hot starts, immediate penetration
- No arc "pop outs"
- No current drop-off during pass
- Uniform fusion, steady rate of metal deposit

200 in 300 400 ampere models

Patented Vickers Magnetic Amplifier . . .

CONTROLARC automatic control is made possible by the patented Vickers Self-Saturating Magnetic Amplifier with exclusive voltage-sensing, feed-back control circuits. Constantly analyzing welding voltage and automatically adjusting welding current to arc changes. Vickers Magnetic Amplifier maintains ideal arc characteristics, through the entire welding range, under all welding conditions.

Voltage and Current Individually Controlled . . .

Separate, complete control of both voltage and current makes it possible to set up any volt-ampere combination within the output range of the particular Controlarc model being used . . . from minimum voltage at minimum current to maximum voltage at maximum current. Only Vickers Controlarc offers complete remote control of voltage and current through the entire welding range.

Full Range Voltage Control . . .

. . . separate from current control, permits choosing the exact arc characteristic for every job and welding condition. Voltage control is full range and stepless, with no limited "average" settings or blind spots. The weldor can select the arc characteristic for a basic welding position and pinpoint the setting for particular conditions.

Downdraft Cooling
No "vacuum cleaner" floor dust pickup.

Rectifiers
Conservatively rated for long life. Special finish protects from corrosive atmospheres.

Rust Protected
Interior surfaces zinc chromated.

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Sealed-in Lubrication of Fan Motor Bearings

Duct-Cooled Transformer
Air ducts in windings for high-efficiency cooling.

Concentrated Weight
Low center of gravity.

Skid Mounted
Portable mounting available.

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NEW LITERATURE

New AWS-ASTM Specifications Advance Standardization of Arc-Welding Electrodes

Two new specifications on arc-welding electrodes have just been issued by the AMERICAN WELDING SOCIETY and the American Society for Testing Materials.

The first of these, *Tungsten Arc-Welding Electrodes* (AWS A5.12-55T), now makes possible standardization of nonconsumable type electrodes used for inert-gas metal-arc welding and for atomic hydrogen welding. It classifies the electrodes into four basic chemical analyses, thus enabling the user to select his tungsten electrodes by composition according to his requirements. The specification also sets up standard sizes, lengths and tolerances of electrodes. In addition, requirements on finish, straightness, quality, marking and packaging are included.

The second specification, a revised edition of the *Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes* (AWS A5.4-55T) includes eight new classes of electrodes. The additions cover the recently developed electrodes which have widened the range of stainless steels, clad steels and dissimilar metals that can now be successfully welded. The new classes covered are: two extra low-carbon grades (E308ELC and E316ELC); two columbium grades (E309Cb and E310Cb); two molybdenum grades (E309Mo and E310Mo); and grades E312 and E318. These, added to the previously established classes, bring the total standard electrode classes to 18. Details are given on test methods, weld metal composition requirements, standard sizes and lengths, packaging and color markings for identification. An appendix is provided to aid prospective users in selecting the electrode class best suited for a particular application.

Copies of these new specifications in pamphlet form are available from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y., at 40 cents each.

Chrome-Moly Electrodes

The Champion Rivet Co. announces the availability of report CM-55, "Chrome - Moly Electrodes, AWS-ASTM Specification SA-316 and SA-298." A copy of this report may be obtained by writing to the company at E. 108th and Harvard Ave., Cleveland, Ohio.

1954 ASTM Proceedings

The 1954 edition of the *ASTM Proceedings* has been published recently. The 1400-page volume records the technical accomplishments of the American Society for Testing Materials for the year 1954. It includes many technical reports and papers together with discussion which has been offered to the Society during the year and accepted for publication in the *Proceedings*.

Copies of the *ASTM Proceedings* may be purchased from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. The price is $12 per copy.

WRC Bulletin No. 22 Welded Tee Connections

The Welding Research Council has just issued Bulletin No. 22, *Welded Tee Connections*, giving strain measurements and hydrostatic tests to destruction of various methods of providing reinforcement of welded tee connections in large diameter gas transmission pipe. The bulletin consists of 24 pages. Price: $1.00 per copy. Limited edition. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Welding Materials Specifications

A comprehensive compilation of materials specifications for the welding industry is now available from Shieldalloy Corp., 99 Park Ave., New York 16, N. Y. The two-color, 37-page book gives chemical and screen analyses for powder metals and alloys, processed minerals and ores, and chemical analyses of metals and alloys. Primarily prepared for the welding rod manufacturing industry, these materials also have a wide range of application in the steel alloying, foundry and ceramics industries. Book is entitled *Shieldalloy Materials for the Welding Rod Industry*.

Hydrogen Contamination in Titanium and Alloys

The first results of an intensive research program by the Air Force into the effects of hydrogen contamination in titanium and titanium alloys have just been made available to industry by the Office of Technical Services, U. S. Department of Commerce, in a report prepared by the Wright Air Development Center.

The research program was initiated because lack of information on the effects of hydrogen contamination had threatened to hinder Air Force application of titanium alloys. This report consists of papers and discussions presented at a technical meeting at WADC in late 1954.

"Hydrogen Contamination in Titanium and Titanium Alloys," Part 1, "Hydrogen Embrittlement in Alpha-Beta Titanium Alloys." Wright Air Development Center, January 1955. 185 pages. (Order PB 111620 from OTS, U. S. Department of Commerce, Washington 25, D. C., price $4.75.) Report of WADC technical meeting Oct. 29, 1954, including papers, discussions and illustrations. Research shows that hydrogen contamination in alpha-beta alloys can cause low ductility in slow strain rate, room temperature tensile tests and premature brittle fracture in room temperature rupture tests. The combination of stress concentrations and hydrogen contamination can lead to a drastic decrease in the load carrying capacity of these alloys. Another result of hydrogen contamination is increased susceptibility to embrittlement as a result of exposure to stress and elevated temperature. At present, a maximum hydrogen content of 125 ppm is suggested as a tolerance for aircraft quality alpha-beta titanium forging alloys. Data are presented which show that in the future it will be possible to produce alloys which have much higher tolerances for hydrogen.

Airco Publications

The Air Reduction Sales Co. has just announced the availability of a new Publication List.

Over 100 welding and cutting technical reprints, textbooks, safety booklets, slide films and movies are briefly described in this 16-page booklet. Convenient order cards, keyed for easy selection, are included for requesting items of interest.

Request a copy by writing Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 60 E. 42nd St., New York, N. Y.

Welding Manual

A New Welding System is the title of a new 32-page technical manual offered by Metal & Thermit Corp., New York, N. Y. The manual is designed as a comprehensive, practical guide to the use of Murex "Croloy" chrome-moly electrodes for the welding of piping and equipment subject to high-temperature, high-pressure service.

An introductory section explains the advantages of the new Croloy system in eliminating underbead cracking, simplifying preheat and postheat operations and reducing the need for stress relieving.

The text describes mechanical properties and welding procedures for each of the four types of electrodes which deposit varying percentages of chromium in the weldment. Graphs detailing stress rupture characteristics and physical properties at various temperatures are included for each of the four electrodes.

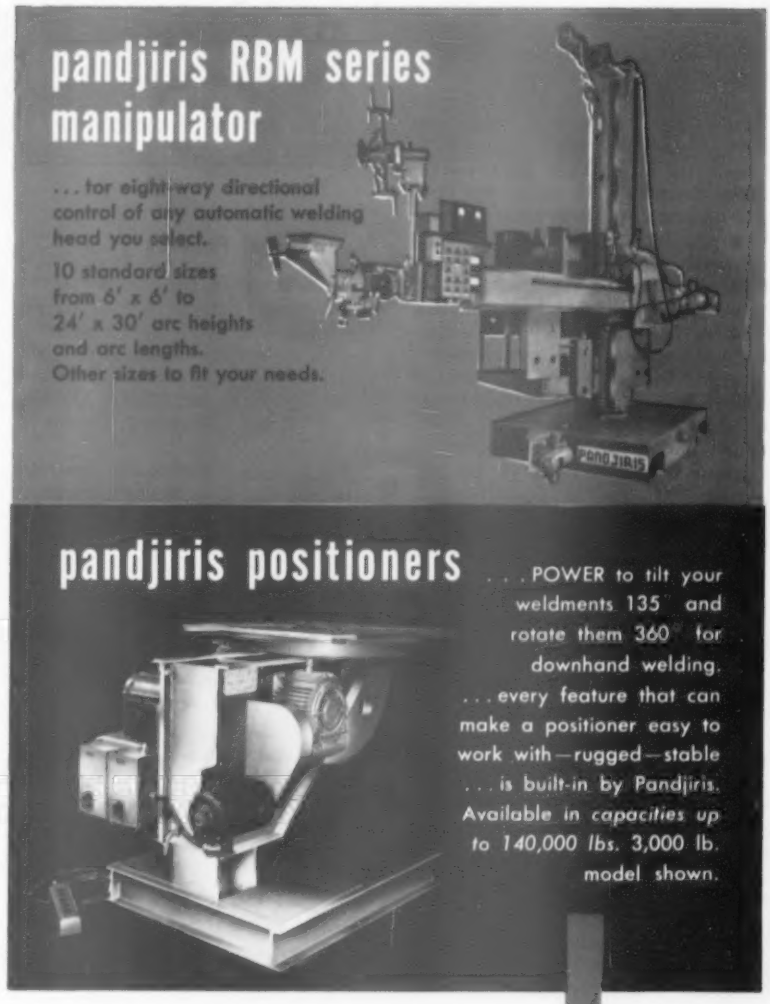
Copies of the manual may be obtained by writing to Metal & Thermit Corp.

Welding Cost Analysis

A production cost study of automatic electric arc welding seams of cylindrical and elliptical vessels or pipe has just been published by the Pandjiris Weldment Co., 5151 Northrup Ave., St. Louis 10, Mo. This bulletin contains six pages and covers the automatic welding of 10 gage to $^3/_4$-in. plate. Eighteen cost factors affecting the cost of welding footage are presented in columnar form to give unit cost. An accompanying graph depicts unit production and cost per day.

The study is presented in a manner which will be of interest to and answer questions of management as well as shop personnel.

The bulletin may be had free of charge by writing to Pandjiris Weldment Co., 5151 Northrup Ave., St. Louis 10, Mo.


pandjiris RBM series manipulator
. . . for eight-way directional control of any automatic welding head you select.
10 standard sizes from 6' x 6' to 24' x 30' arc heights and arc lengths.
Other sizes to fit your needs.
pandjiris positioners
. . . POWER to tilt your weldments 135° and rotate them 360° for downhand welding.
. . . every feature that can make a positioner easy to work with—rugged—stable . . . is built-in by Pandjiris.
Available in capacities up to 140,000 lbs. 3,000 lb. model shown.
pandjiris turning rolls
. . . POWER to turn cylinders continuously for circumferential seams . . . to position them for horizontal welds.
No crane or manual work!
Pandjiris builds 'em right . . . in capacities up to 400,000 lbs.
THE WORLD'S LARGEST MANUFACTURERS OF "AUTO-WELD-MATONS"®
PHONE OR WRITE TODAY
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DESIGNERS AND MANUFACTURERS OF PRODUCTION WELDING EQUIPMENT
5151 NORTHRUP AVE., ST. LOUIS 10, MO., U. S. A.
efficient positioning of all three
THE MAN
THE ARC
THE WORK

Simplified Drafting

A 36-page booklet on "Simplified Drafting" has just been released by the American Machine & Foundry Co. Authored by J. H. Bergen, Standards Administrator of AMF's Engineering Division, the 8½ x 11-in. paper-bound booklet presents in a clever yet dramatic manner 11 common-sense rules for simplifying drafting practices.

Through the medium of sample drawings of engineered parts and assemblies, the 11 rules—from the use of word descriptions for simple parts to making free-hand drawings wherever possible—are illustrated and a straight-forward comparison made between traditional and simplified methods.

For additional information write on company letterhead to J. H. Bergen, American Machine & Foundry Co., General Engineering Laboratory, 11 Bruce Place, Greenwich, Conn.

Gas Welding Torches

Complete data and specifications about Marquette's five entirely new oxy-acetylene torch sets are given in separate colorful brochures.

The brochures tell about the heavy-duty Super-jet, the medium duty Star-jet, the light duty Aero-jet and the Jet-o-matic (an automatic version of the aircraft torch) and the Master cutting equipment. The advantages of aluminum handle construction are described as well as the radically new design which make these torches stronger, lighter and cooler operating.

For your free copies, write Marquette Manufacturing Co., 307 E. Hennepin Ave., Minneapolis, Minn., or see your local Marquette distributor.

Electrode Comparison Chart

The Electrode Division of the McKay Co. has just issued a new Comparison Chart which lists electrode classifications and all major manufacturers' electrodes which fall into each individual class.

The welding electrodes covered include all classes of mild steel, stainless steel and special-purpose electrodes used in manufacturing and maintenance. Also covered is the new McKay line of hard-surfacing electrodes.

Welding engineers, welding supervisors and purchasing personnel will find this Comparison Chart useful in matching brand name electrodes with the AWS class or the AISI grade.

For a copy of the McKay Comparison Chart, write to the McKay Co., 303 McKay Bldg., Pittsburgh 22, Pa.

Help Your Society to Grow—

Be An Active Member!

Mechanical Presses

A new two-page, two-color 8½ by 11-in. illustrated bulletin (EW-3) describing a new line of inverted mechanical presses for a wide variety of spot and projection welding operations is now available from Expert Welding Machine Co., 17144 Mt. Elliott Ave., Detroit 12, Mich.

The bulletin describes and illustrates with cutaway views the design features of the presses which have a compact, self-contained mechanical knee unit that facilitates the welding of deep drawn parts or assemblies where adequate clearance for loading and unloading is required.

•

REVIEWS OF NEW BOOKS

Engineering Mechanics

Engineering Mechanics, 2nd ed., by Archie Higdon, U. S. Air Force Academy, and William B. Stiles, University of Alabama. Price $7.95, 585 pages. Published by Prentice-Hall, Inc., 70 Fifth Ave., New York 11, N. Y.

Like the first edition, this book is aimed at having engineering students grasp mechanics, not as a series of formulas and manipulative operations, but rather as a well comprehended mechanism for stripping problems of their extraneous confusing aspects, so as to be able to break them down into relatively simple, easily analyzed elements.

Text places an emphasis on an understanding of the principles employed in the solution of problems rather than on a rate process of substitution in numerous formulas.

General Metallurgy

Metalurgia General by Prof. E. Jimeno, University of Madrid, Spain, and F. R. Morral, Kaiser Aluminum & Chemical Corp. Price, 375 pesetas for the two volumes—1323 pages, 6¾ x 9¾. Published by Imprenta Saez, Madrid, Spain. Distributor: Aguilar.

This two-volume book was issued originally as a publication of the University of Madrid. It is intended to help train scientists, engineers and technicians in Spanish-speaking countries, as well as to provide a handy reference for consultants and anyone else interested in metals.

The whole text, consisting of 37 chapters covering the various phases of metallurgy, is complemented with line drawings, photographs and tables. One complete chapter is devoted to welding and cutting of metals.

Painting Manual

Two volumes of the *Steel Structures Painting Manual* have been published recently by the Steel Structures Painting Council, 4400 Fifth Ave., Pittsburgh 13, Pa.

Entitled *Good Painting Practice* and *Systems and Specification* the volumes have been prepared by a staff of specialists and edited by Dr. Joseph Bigos, Senior Fellow of Mellon Institute, and Director of Research of the Steel Structures Painting Council.

Volume 1 describes the best of the current surface preparation and painting practices in various industries. The manual is written from the viewpoint of paint users. It is a practical encyclopedia of economical and satisfactory painting methods, rather than a technical treatise on paint formulation. The book contains 18 chapters plus a foreword, glossary and index.

Volume 2 contains very specific recommendations on painting a tremendous variety of steel structures and surfaces in various exposures. Complete guides and indexes make it easy for engineers, architects, fabricators and maintenance supervisors to quickly, easily and *correctly* specify complete paint jobs for new work or maintenance painting. Volume 2 includes complete specifications for surface preparation, pretreatment, paint application, paints and paint systems. *Good Painting Practices* consists of 432 pages and *Systems and Specifications* consists of 300 pages, 8½ x 11 in., case bound in leatherette with hard covers. Copies of either volume may be ordered from the Council at a cost of $6.00 each, postage paid.

Steel Structures Painting Council is an impartial, nonprofit organization supported by voluntary contributions from organizations concerned with the manufacture, specification or use of paints or other coatings for the protection of steel surfaces including weldments. It was organized in 1950 through the efforts of the American Institute of Steel Construction.

Current Welding Literature

ACCIDENT PREVENTION. Second Look at Welding Hazards, P. C. Ziemke. Safety Maintenance & Production, vol. 108, no. 4 (Oct. 1954), pp. 22–24, 86–87.

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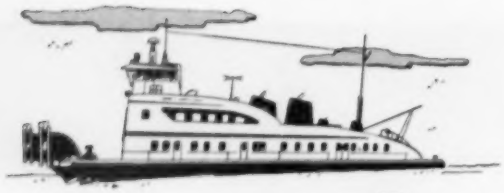

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SUPPLEMENT TO THE WELDING JOURNAL, JULY, 1955

STATIC TESTS OF WELDED ALUMINUM ALLOY BEAMS

Experimental program develops useful data for establishing design procedures for welded structures of aluminum alloys containing up to about 6% magnesium

BY MARSHALL HOLT AND R. B. MATTHIESEN

I. Introduction

Continuing research in the aluminum industry has led to alloys and welding procedures that can be combined to make built-up structures with sufficient strength to attract the attention of designers in many fields. At present, the weldable alloys which are most attractive to the structural engineer are those containing up to about 6% magnesium. The tensile strengths of these alloys increase with the magnesium content so that, in the annealed condition, the alloy containing about 5% of this constituent, X5356, develops a tensile strength of at least 38,000 psi, a yield strength of 16,000 psi and an elongation in 2 in. of 17%. The strengths of this alloy can be increased by cold working but not by thermal treatments.

Aluminum alloys containing up to 5% magnesium have been used successfully in many marine structural applications. Both Lloyd's of London and Societé Veritas have issued specifications and design rules for their use. In this country, the nonheat-treatable alloys in the magnesium series and a heat-treatable alloy containing 1.0% magnesium and 0.6% silicon, 6061, are used in marine applications involving welding. The U. S. Army, Navy and Air Force have approved specifications for the nonheat-treatable alloys 5154 and X5356 containing 3.5 and 4.5% magnesium, respectively, and for the heat-treatable alloy 6061 containing 1.0% magnesium and 0.6% silicon.

Alloy 5154 (GR40A) is covered by Case 1174-2 of the Code issued by American Society of Mechanical Engineers for Boilers and Pressure Vessels, and recent articles have described the application of this alloy in the design of pressure vessels.[1, 2] Allowable stresses for heat-treatable alloy 6061 (GS11A) are given in Case 1185 of the Boiler and Pressure Vessel Code. Additional data, including specified tensile properties and composition limits and a cross reference of the various designations and specifications for these alloys, are given in Tables 1 and 2.

In order to obtain some general data that would be useful in establishing design procedures for welded structures of these alloys, an experimental program was undertaken at the Aluminum Research Laboratories to make static tests on beams built up by welding certain aluminum alloys. One of the important points covered by this investigation concerns the effects of the welding heat on the properties of the materials and hence on the strengths of the beams. For comparison purposes a series of extruded beams was also tested.

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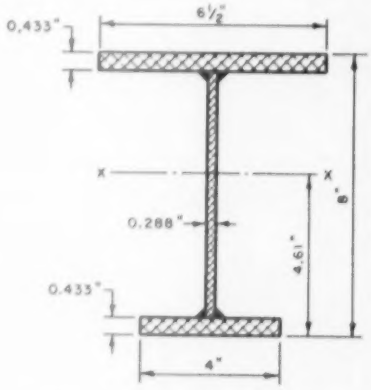
II. Specimens

The dimensions and section elements of the 8-in. unsymmetrical I-section selected for the beams tested in this program are shown in Fig. 1. The beams were tested with the wider flange in compression in an effort to avoid the problems of lateral buckling within the elastic-stress range. The section elements given are average values determined with an Amsler mechanical integrator from tracings of the actual cross



$A = 7.08^2$, $I_{XX} = 77.0\ IN^4$, $S_{XX} = 16.7\ IN^3$

Fig. 1 Cross section of test specimens

Note: For the extruded beams, the section was obtained by trimming both flanges of an 8-in. by 8-in. wide-flange section

Table 1—Specified Composition Limits of Weldable High-Strength Aluminum Alloys

Alloy: Commercial designation — New	Alloy: Commercial designation — Old	Alloy: ASTM designation	Specifications: Army, Navy and Air Force approved	Specifications: ASTM	Heat treatable	Chemical compositions, %								
						Cu	Fe	Si	Mn	Mg	Zi	Cr	Ti	Be
5154	A548	GR40A	Mil. A-17357-A (Ships)	B178-54T	No	0.10	*	*	0.10	3.1–3.9	0.20	0.15–0.35	0.20	
X5356	XC56S	GM50A	Mil. A-18024 (Ships)		No	0.10	†	†	0.05–0.20	4.5–5.5	0.10	0.05–0.20	0.06–0.20	0.0005
6061	61S	G81IA	47A12b	B178-54T	Yes	0.15–0.40	0.70	0.4–0.8	0.15	0.8–1.2	0.20	0.15–0.35	0.15	

* Iron plus silicon = 0.45. † Iron plus silicon = 0.50.

Table 2—Specified Tensile Properties of Weldable High-Strength Aluminum Alloys

Alloy and temper	*Thickness, in.*	*Ultimate strength minimum, except as noted, psi*	*Yield strength (offset = 0.2%) minimum, except as noted, psi*	*Elongation minimum, except as noted, %*
5154-0	0.20–2.000	30,000	11,000	12*
-H112	0.162–2.000	30,000	11,000	8
-H32	0.020–2.000	36,000	26,000	5*
-H34	0.020–2.000	39,000	29,000	4*
-H36	0.020–2.000	42,000	32,000	3*
-H38	0.020–2.000	45,000	35,000	3*
X5356-0	0.250–3.000	38,000	16,000	17
-H112	0.250–0.500	40,000	22,000	10
-H112	0.501–1.000	38,000	20,000	12
-H112	1.001–3.000	38,000	16,000	12
-H321	0.250–2.000	42,000	26,000	12
6061-0	0.010–3.000	16,000†	6,000†	14*
-T6	0.010–3.000	42,000	35,000	8*

* Varies with thickness, only minimum value shown.
† Expected values, not guaranteed.

sections of the specimens. The values for all specimens are within +4 and −6.5% of the average.

The six types of specimens which were tested are illustrated in Fig. 2.

The specimens of Type A were fabricated from three pieces of sawed plate by attaching the two flange plates to the web plate by means of fillet welds. For the alloys that cannot be strengthened by heat treatment, it would be expected that this method of fabrication could utilize the relatively high strengths of cold-worked plate material even if the heat of welding would erase a small part of the effects of cold working. Plates of 5154-H34, X5356-H34, X5356-H112 and 6061-T6 were used in making these specimens.

The specimens of Type B were similar to those of Type A in that they were built up by welding. In addition, however, a transverse butt joint was made at the center of each specimen and

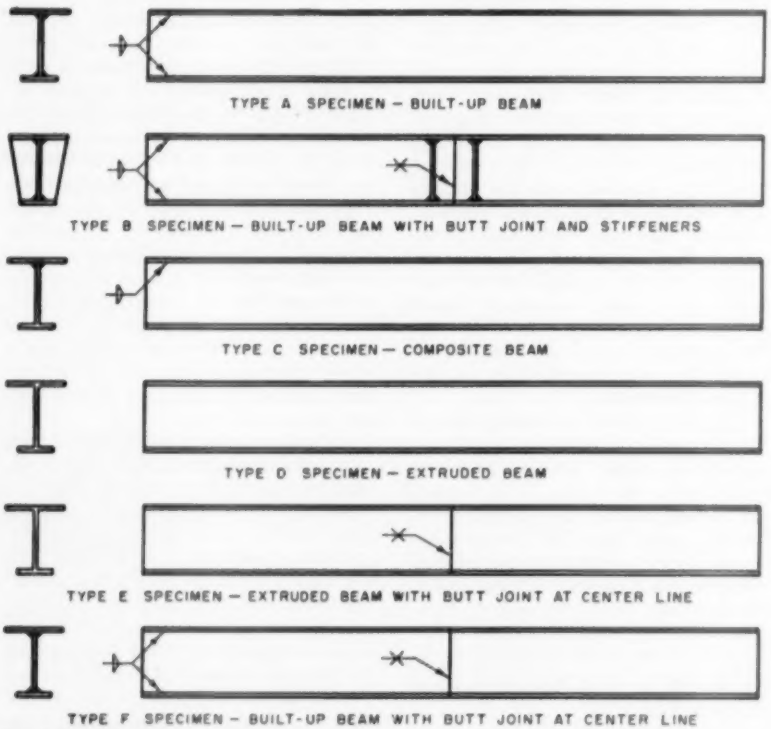

TYPE A SPECIMEN — BUILT-UP BEAM
TYPE B SPECIMEN — BUILT-UP BEAM WITH BUTT JOINT AND STIFFENERS
TYPE C SPECIMEN — COMPOSITE BEAM
TYPE D SPECIMEN — EXTRUDED BEAM
TYPE E SPECIMEN — EXTRUDED BEAM WITH BUTT JOINT AT CENTER LINE
TYPE F SPECIMEN — BUILT-UP BEAM WITH BUTT JOINT AT CENTER LINE

Fig. 2 Types of specimens

Table 3—Results of Tensile Tests of Material*

Alloy and temper	Product	Properties of material: Tensile strength, psi	Yield strength (offset = 0.2%), psi	Elongation, % in 2 in.
5154-0	Extruded beam	36,200	16,800	27
-F	Extruded	39,600	20,800	22
-H34	Plate	44,600	35,900	16
X5356-0	Extruded beam	41,200	18,700	35
-F	Extruded beam	47,000	24,000	22
-H112	Plate	46,500	28,700	23
-H34	Plate	52,700	39,900	16
6061-0	Extruded beam	20,000	9,700	29
-T6	Extruded beam	39 600	37,400	20
-T6	Extruded beam	50,900	47,100	16
-T6	Plate	44,400	40,600	19

* Tested in accordance with ASTM Tentative Methods of Tension Testing Metallic Materials, E8–52T, ASTM Book of Standards, Part 2, p. 1208.

two sets of transverse stiffeners were welded to both flanges and the web near the center. These stiffeners were not added to prevent local failures but to simulate a structural detail which would concentrate a large amount of welding in a region of high stress.

The specimens of Type C were fabricated from extruded tees of alloy 6061-T6 and compression flanges of cold-rolled plates of the magnesium-bearing alloys. These specimens were intended to simulate structures involving a combination of heat-treated 6061-T6 structural shapes and cold-rolled plates of nonheat-treatable alloys.

The specimens of Type D were extruded beams with no welds. Although the extrusion process might introduce a small amount of cold work, the strengths of the as-extruded material cannot be counted on to be greater than those of annealed material. Both as-extruded and annealed specimens of the nonheat-treatable alloys were tested. Beams of the heat-treatable material were tested in the fully heat-treated condition as well as in the annealed condition.

The specimens of Type E were similar to those of Type D in that they were extruded; however, a transverse butt joint was made by welding as was the case with the Type B specimens.

Two specimens of Type F were added after the failures of the specimens of Type B had been observed. These two specimens were built up by welding and contained a transverse butt joint; however, they had no stiffeners. Special back-chipping techniques were used with these specimens in an attempt to achieve complete penetration of the butt weld at the web-flange junction.

The tensile properties of the materials were determined in accordance with ASTM Standard Methods.[3] The values given in Table 3 are averages for various lots of material and represent the flanges of the extruded shapes and the plate used for the flanges of the built-up specimens. In the case of the 6061-T6 extruded shapes, two sets of tensile properties are given because two pieces from the lot had properties considerably higher than the average for the rest of the lot. With this division of the 6061-T6 shapes, the variations of the individual pieces from the average for the lot were less than ±4%. The values given for alloys 5154 and 6061 meet the specification requirements and, except for the one lot of 6061 shapes, they agree very closely with published typical values.[6] The values for alloy X5356 also meet the specification requirements, but because of the limited production there are no published typical values.

All the welding was done by the Alcoa Process Development Laboratories using the semiautomatic inert-gas consumable-electrode process. Prior to making the welds, the parts were cleaned by degreasing and wire brushing. The pieces were not preheated and were cooled to a temperature tolerable to the touch before starting the subsequent pass.

Each of the flange-to-web fillet welds was deposited in the down-hand position in two passes without prior edge preparation. In preparation for making the transverse butt welds, the edges were beveled to form a 60-deg vee with a $\frac{1}{16}$-in. abutting lip. The specimen was rotated so that all the welding was done in the down-hand position. The initial pass was back-chipped before deposition of a bead on the reverse side. The transverse joints in the two specimens of Type F and one of Type E were prepared using special back-chipping techniques in an attempt to obtain complete penetration at the junction of the web and flange, since the failure of the other specimens with transverse joints showed that complete penetration had not been obtained with simple back chipping.

A steel jig was used to maintain the alignment of the parts during welding. For the specimens of Types A, B, C and F the flange plates were deformed in the jig so that the flanges would be flat after welding. With few exceptions, the warpage and distortion of the finished specimens were within the commercial tolerances for straightness, twist and flatness of similar extruded shapes. It is believed that the distortions of the specimens had no significant effect on the structural behavior of the specimens.

Qualification tests for welders and welding procedures were made with full- and reduced-section tensile specimens, longitudinal-shear specimens and free-bend specimens made from the flange-plate materials. The results of these tests, given in Table 4, are in close agreement with the results of other investigations.[4] The strengths of the reduced-section tensile specimens of alloys 5154 and 6061 meet the requirements of Section IX of the ASME Code for Boilers and Pressure Vessels. The reduced-section tensile specimens of

Table 4—Results of Tests of Welds*

Base metal	Filler metal	Full-section tensile test: Tensile strength, psi	Yield strength,† psi	Elongation, % in 4 in.	Reduced section tensile test, tensile strength, psi	Free bend test, elongation, %	Longitudinal-shear test, shear strength, psi	lb/in.‡
5154-H34	5154	39,500	19,600	11	33,300	48	16,300	4800
X5356-H112	5356	45,300	23,100	21	40,800	53	20,000	5800
X5356-H34	5356	46,500	24,100	12	40,400	58	19,700	5700
6061-T6	4043	29,500	20,200	6	28,300	16	16,400	5200
6061-T6	5356	32,100	20,900	6	29,700	18	14,900	4300

* Tested in accordance with ASTM-AWS Standards.
† Stress to produce 0.2% offset in a 4-in. gage length centered across the weld.
‡ Full fillet with 0.433-in.-thick plate.

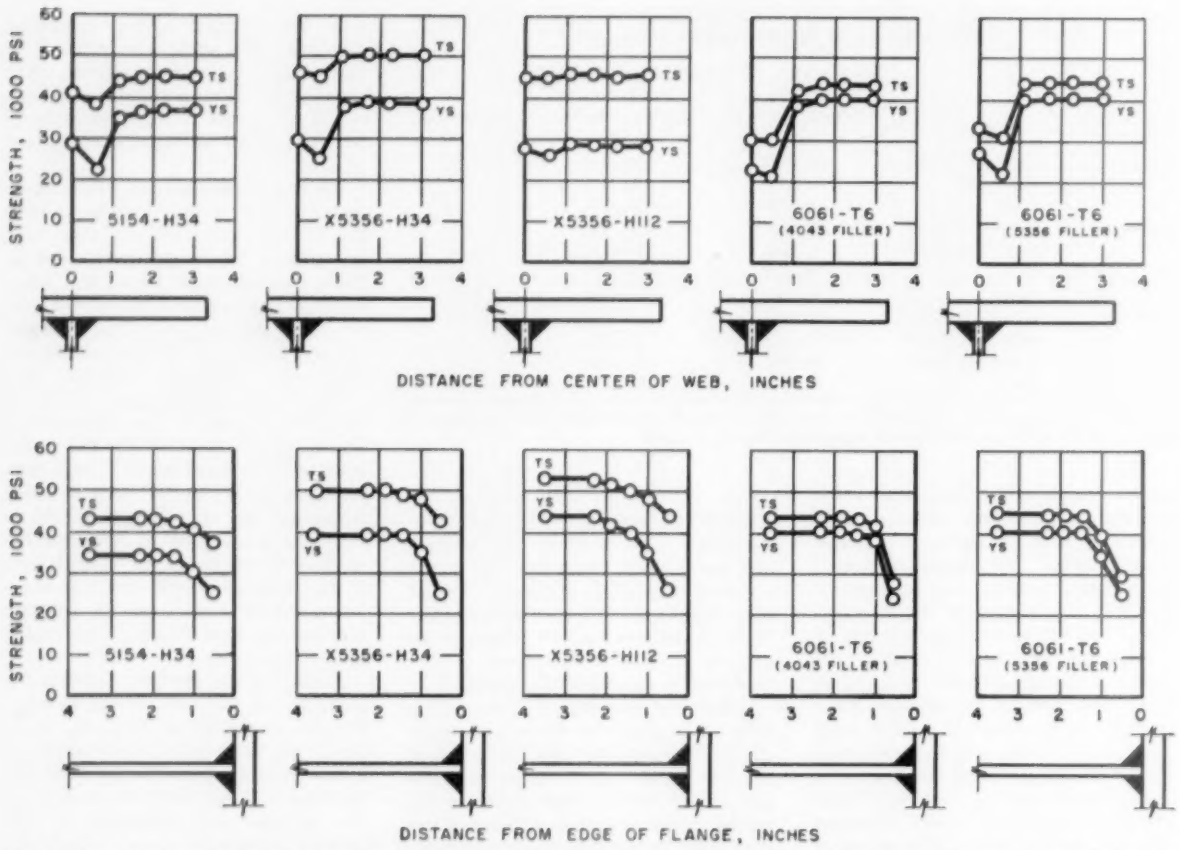


Fig. 3 Results of tensile tests to determine the extent of the heat-affected zone. TS = Tensile strength. YS = Yield strength

the nonheat-treatable alloys broke in the region of the deposited metal; whereas, the full-section specimens of these alloys and also both types of specimens of 6061-T6 broke near the weld in the heat-affected zone. A comparison of the results from the reduced-section specimens with the original tensile strengths indicates the following joint-efficiency factors:

Base metal	5154-H34	X5356-H112	X5356-H34	6061-T6	6061-T6
Filler metal	5154	5356	5356	4043	5356
Joint-efficiency, %	75	88	77	64	67

It should be noted that the tensile strengths of the reduced-section specimens are greater than the corresponding specified tensile strength of the material in the annealed condition.

As indicated previously, it is to be expected that the heat of welding would erase some of the effects of tempering in a narrow zone along the welds. Both hardness surveys made on $^1/_8$-in.-thick slices sawed from the ends of the specimens of Types A and C and tensile tests made on specimens taken at various distances from the welds in the beams of Type A were used to determine the width of the heat-affected zone. The results of the tensile tests are shown in Fig. 3 and no appreciable differences can be noted in the widths of the heat-affected zones for the various alloys. Both types of tests indicated that the heat-affected zone in the flanges extended to approximately $^3/_4$ in. (two times the thickness) and in the web to approximately $1^1/_4$ in. (five times the thickness) from the center of the weld. The widths of heat-affected zone indicated by these data are essentially the same as those indicated by other tests,[5] but the techniques used in both investigations probably tend to minimize the width of the heat-affected zone. Without control of interpass temperatures or with higher rates of deposition, the width of the heat-affected zone might be significantly greater than these tests indicate.[6, 7]

III. Test Procedure

The beam tests were made in an Amsler hydraulic-type testing machine using the intermediate 100,000-lb load range. The periodic calibrations of this machine indicate that the loads are in error by less than one percent for the upper 90% of the load range. The specimens were loaded at the third-points of a span of 73.5 in., the ends being considered simply supported by the fixtures shown in Fig. 4. Because of the large deflections developed in these tests, the loading struts were allowed to slide on the upper loading head. It is believed that this arrangement minimized the secondary effects that might have resulted had no movement been permitted.

The load was applied in increments until failure occurred, deflection measurements using mirror-backed scales and a taut wire being made at mid-span and at the load points for each increment. An autographic load-deflection curve was also obtained.

IV. Results of Beam Tests

The results of the beam tests are presented as load-deflection curves in Figs. 5, 6, 7 and 8 and are summarized in Table 5. Table 5 contains a description of the specimens and indicates the parent metal and filler metal alloys.

(a) Built-up and Extruded Beams (Without Transverse Joints)

The load-deflection curves for the built-up and extruded beams (Types A and D, respectively) are shown in Fig. 5. The straight line marked "computed" in this and in subsequent

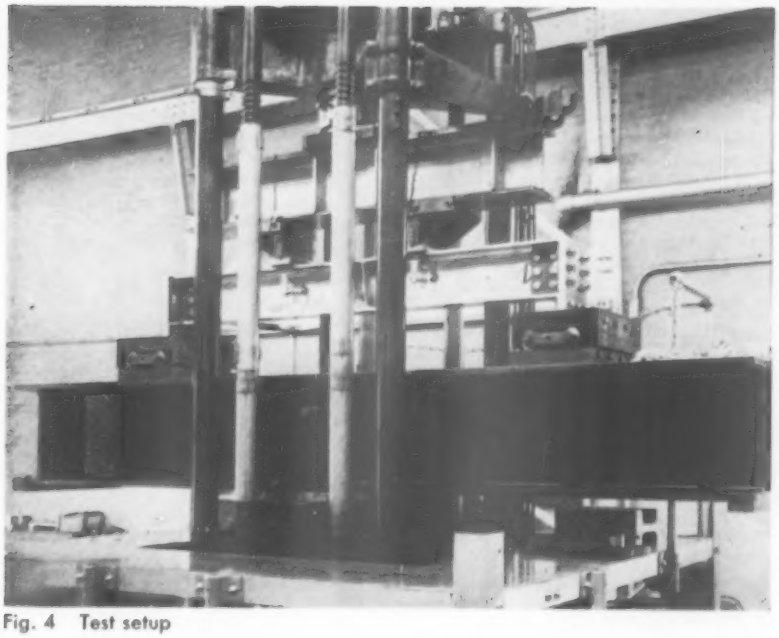


Fig. 4 Test setup

load-deflection diagrams is based on computations which include both bending and shear deflections. Failure of these specimens occurred by lateral buckling after rather large vertical deflections.

In all cases, the measured and computed deflections agree very well in the initial portion of the curves. For the built-up beams, the departure of the curves of measured deflections from the computed straight line is gradual for loads between about 20,000 and 40,000 lb, the latter value being about two-thirds of the ultimate load. The curves for the extruded beams of 5154 and X5356 and for the annealed extruded beam of 6061 depart rather rapidly from the computed straight line.

The ultimate loads for the built-up specimens of 5154 and X5356 plates are approximately 1.5 times that of the corresponding extruded beam in the annealed condition. The welded beam of 6061-T6 plates supported in ultimate load approximately 2.1 times that of the extruded 6061-0 beam but only 90% of that of the extruded 6061-T6 specimen. Of the two beams built up of 6061-T6 plates, the one welded with 5356 filler metal was slightly stronger (3%) than the one welded with 4043 wire. There is no significant difference in the deflections under the maximum loads.

Of the built-up specimens, the one made of X5356-H34 plates supported the largest ultimate load, 63,500 lb, which is only 3250 lb or about 5% less than the ultimate load supported by the 6061-T6 extruded beam. The ultimate loads for the other built-up specimens were approximately 59,000 lb. The computed shear stresses in the webs near the flanges were 14,100 psi for the X5356-H34 built-up specimen and

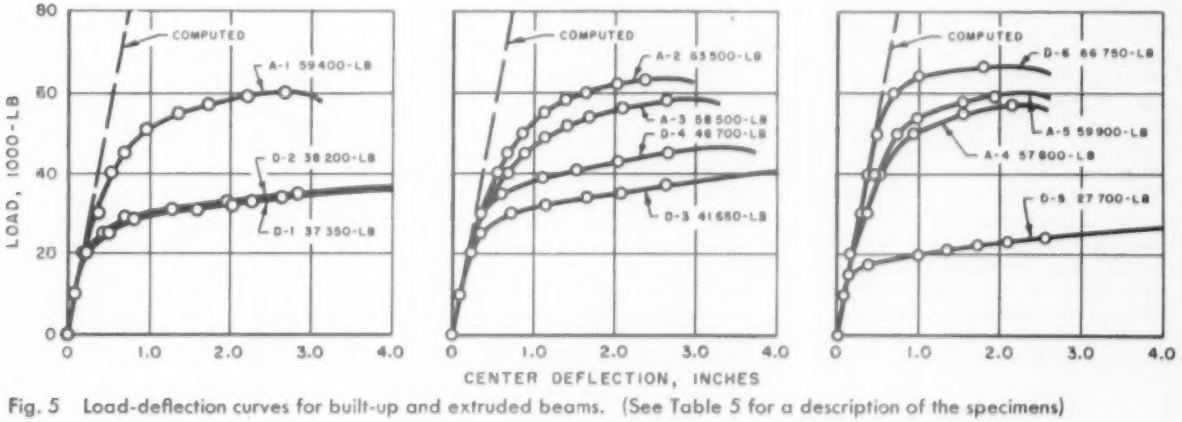


Fig. 5 Load-deflection curves for built-up and extruded beams. (See Table 5 for a description of the specimens)

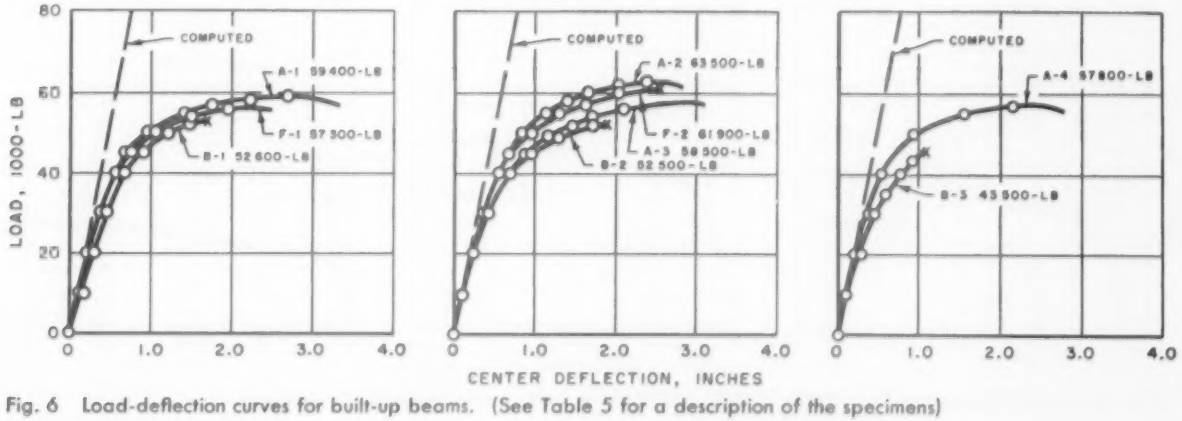


Fig. 6 Load-deflection curves for built-up beams. (See Table 5 for a description of the specimens)

about 13,000 psi for all the others. Since the shear strength of 6061-0 is considered to be about 12,500 psi, it appears that a failure governed by the shear strength of the web might have been impending.

(b) Built-up Beams with Transverse Joints

The load-deflection curves for the built-up beams with transverse joints (Types B and F) are plotted in Fig. 6 with those for the beams without joints (Type A). Since most of the specimens with transverse joints fractured through a region of incomplete fusion, a comparison of the ultimate loads with those from corresponding specimens without transverse joints may not be a valid indication of the effects of the heat applied in making the joint and attaching the transverse stiffeners.

At intermediate loads, the deflections of specimens B1 (5154-H34) and B3 (6061-T6) were greater than those of the corresponding specimens without a transverse joint. On the other hand, for loads up to 40,000 lb the deflections of specimens F1 (5154-H34), F2 (X5356-H34) and B2 (X5356-H112) agree very well with those of the corresponding specimens without transverse joints. A comparison of the load-deflection curves for specimens B1 and F1, indicates that the special techniques used in making the Type F specimens were effective in increasing the ultimate load. Specimen F1 (5154-H34) failed by lateral buckling as did the corresponding specimen without a joint. The difference in the ultimate loads was only about 3%. At intermediate loads, the deflections of specimen B1, with stiffeners, were greater than those of F1, probably because of the greater extent of the heat-affected zone. Even with the special techniques, specimen F2 (X5356-H34) failed by fracture through a small region of incomplete fusion in the joint; however, the maximum load and the deflection at failure were close to the corresponding values for the specimen without a transverse joint.

Table 5—Summary of Beam Test Results

Spec.	Description	Alloy and temper	Filler metal	Ultimate Load, lb	Ultimate Stress,* psi	Deflection,† in.
A-1	Built-up beam	5154-H34	5154	59,400	43,600	2.8
B-1	Built-up beam with transverse joint and stiffeners	5154-H34	5154	52,600	38,600	1.8
D-1	Extruded beam	5154-0	...	37,350	27,400	4.6
D-2	Extruded beam	5154-F	...	38,200	28,000	4.2
E-1	Extruded beam with transverse joint	5154-F	5154	39,700	29,200	3.9
F-1	Built-up beam with transverse joint	5154-H34	5154	57,300	42,000	2.3
A-2	Built-up beam	X5356-H34	5356	63,500	46,600	2.6
A-3	Built-up beam	X5356-H112	5356	58,500	42,900	3.0
B-2	Built-up beam with transverse joint and stiffeners	X5356-H112	5356	52,500	38,500	1.7
D-3	Extruded beam	X5356-0	...	41,650	30,500	4.8
D-4	Extruded beam	X5356-F	...	46,700	34,300	3.5
E-2	Extruded beam with transverse joint	X5356-F	5356	46,500	34,100	3.3
F-2	Built-up beam with transverse joint	X5356-H34	5356	61,900	45,400	2.5
A-4	Built-up beam	6061-T6	4043	57,800	42,400	2.4
A-5	Built-up beam	6061-T6	5356	59,900	44,000	2.6
B-3	Built-up beam with transverse joint and stiffeners	6061-T6	4043	43,500	31,800	1.0
D-5	Extruded beam	6061-0	...	27,700	20,300	6.2
D-6	Extruded beam	6061-T6	...	66,750	49,000	2.3
E-3	Extruded beam with transverse joint	6061-0	4043	25,400	18,600	4.5
E-4	Extruded beam with transverse joint	6061-T6	4043	39,200	28,800	0.5
E-5	Extruded beam with transverse joint	6061-T6	5356	46,350	33,900	0.7
E-6	Extruded beam with transverse joint	6061-T6	5356	43,300	31,800	0.6
C-1	Composite beam	6061-T6 and 5154-H34	5154	66,000	48,300	2.3
C-2	Composite beam	6061-T6 and X5356-H34	5356	70,900	51,900	1.7
C-3	Composite beam	6061-T6 and X5356-H112	5356	65,800	48,300	1.7

* Computed from elastic theory.
† Deflection at ultimate load.

(c) Extruded Beams with Transverse Joints

The load-deflection curves for the extruded beams with transverse joints (Type E) are shown in Fig. 7 with those for beams without transverse joints (Type D). It appears that the introduction of the transverse joint had no significant effect on the behavior or

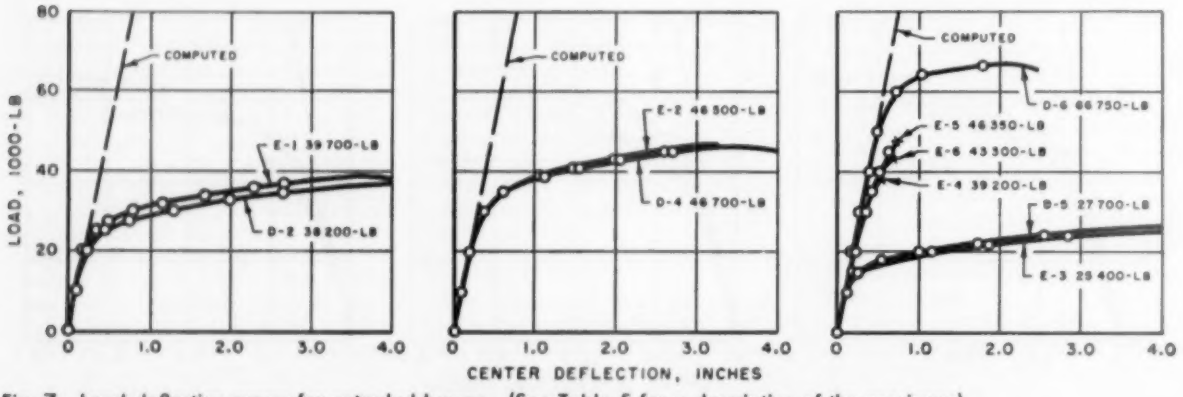


Fig. 7 Load-deflection curves for extruded beams. (See Table 5 for a description of the specimens)

strengths of the beams in the annealed temper; however, the 6061-T6 beams with transverse joints behaved much differently than the corresponding plain beam. The load-deflection curves for Specimens E4, E5 and E6 depart from the initial straight line at about the same load as does the curve for the annealed beam. This reflects the behavior of the material in the heat-affected zone. In the case of Specimens E4 and E5 the fractures passed through a region of incomplete fusion. The difference in beam strengths of Specimens E4 and E5 is about the same as the difference in the tensile strengths of the reduced-section specimens, the higher strengths being obtained with specimens with 5356 filler metal.

Specimen E6 was obtained by removing the heat-affected material from Specimen E5 after it had been tested and remaking the transverse joint. Special back-chipping techniques were used, as with the two Type F specimens, in an effort to obtain complete penetration in the butt weld. Since the calculated maximum stresses in the test of Specimen E5 were below the yield strength of the base material, the original test should have had no significant effect on the results of the second test. Specimen E6 also failed by a sudden fracture but through the heat-affected material adjacent to the weld. Since the behavior and strengths of Specimens E5 and E6 are so nearly the same, it appears that the zone of incomplete fusion had only a small effect on the strength of Specimen E5. In other words, heat of welding is as effective in reducing the strength of 6061-T6 beams as is the notch caused by small regions of incomplete fusion.

Whereas the heat of welding the transverse joint appears to have had no significant effect on the deflections of the annealed specimens, there is a difference in the deflections of the beams made from the harder materials, as can be seen in Figs. 6 and 7. It is reasonable to believe that the larger deflections of the specimens with joints and stiffeners (Types B and E) result from the effects of the heat of welding on the properties of the materials. Only in the case of the 6061-T6 beams did the heat of welding the transverse joint have a significant effect on the ultimate strength of the beams with complete penetration in the butt joint. It is reasonable to believe that if a structure can be made in which the heat-affected zones and the regions of high stress do not coincide, the effects of the heat of welding will be unnoticed.

(d) Composite Beams

The tensile and yield strengths of the extruded shapes used in the composite beam with a 5154-H34 plate (C1) were similar to those of the 6061-T6 extruded beam (D6) and, as indicated in Tables 1 and 2, agreed very closely with the specification requirements. On the other hand, the 6061-T6 shapes joined to X5356-H112 and X5356-H34 plates had tensile and yield strengths about 10,000 psi greater but the elongation was about 4 percentage points less than those of Specimens C1 and D6. The load-deflection curves of the composite beams are given in Fig. 8, certain of the curves for other beams being repeated for comparison. The three composite beams failed by lateral buckling after a rather large vertical deflection. The curves for the extruded 6061-T6 beam (D6) and the composite beam with a flange of 5154-H34 (C1) are very much alike; the ultimate load for the built-up beam of 5154-H34 (A1) is 10% lower but the deflection at ultimate load is about 20% greater.

The composite beams, Type C, with X5356 compression flanges, supported greater ultimate loads than the corresponding built-up beams, Type A, but approximately the same load as the extruded 6061-T6 beam (D6) in spite of the difference in the properties of the 6061-T6 portions of the beams.

Under the maximum loads, the computed shear stresses in the webs adjacent to the welds were about 15,000 psi. This value is above the typical shear strength of 6061-0 (12,500 psi).

(e) Yield Strengths of the Beams

In tensile tests of materials, the yield strength is arbitrarily defined for quality-control purposes as the stress corresponding to 0.2% offset strain; however, no standard definition of yield strength has been established for welded joints because the shape of the stress-strain curve is affected by the relative amounts of parent and heat-affected materials within the gage length. Thus, the value of yield strength would be a function of the gage length. By similarity, the yield strength of a homogeneous prismatic beam might be taken as the stress corresponding to some value of offset beam deflection, for example, 0.1% of the span length. Transverse welded joints in beams would influence the value of beam yield strength in much the same manner that similar joints in plate influence the tensile yield strength.

The load-strain as well as the load-deflection relations were determined for the 6061-T6 specimen of each type. The strains at the center of the span were measured with a Berry strain gage using a 2-in. gage length. In the beams with transverse joints, the gage length included the weld. The strain and deflection data are plotted together in Fig. 9. The loads corresponding to measured offset strains of 0.2% are indicated by the short hash mark on the load-strain curves and the offset deflections corresponding to these indicated yield loads are similarly indicated on the abscissa axis. The indicated offset deflections are:

Specimen	*Offset deflection, in.*
A4	0.15
B3	0.03
C2	0.17
D6	0.13
E3	0.02

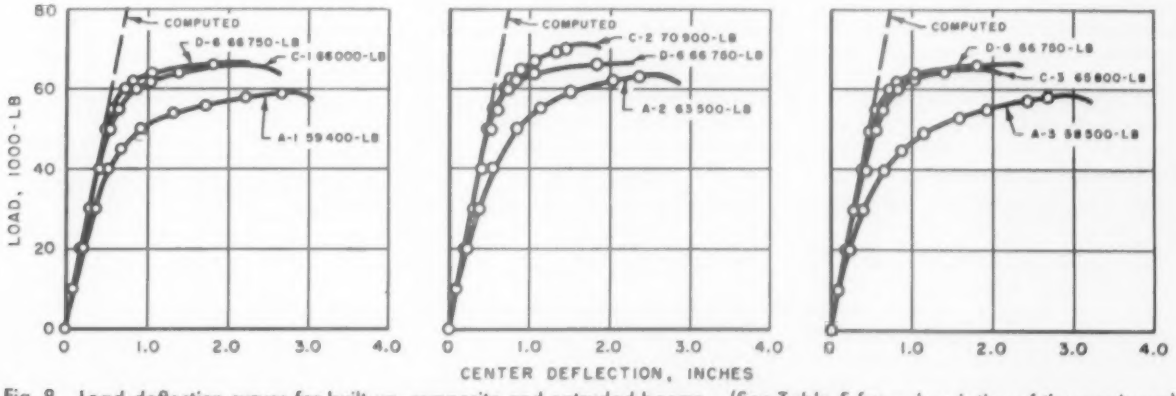


Fig. 8 Load-deflection curves for built-up, composite and extruded beams. (See Table 5 for a description of the specimens)

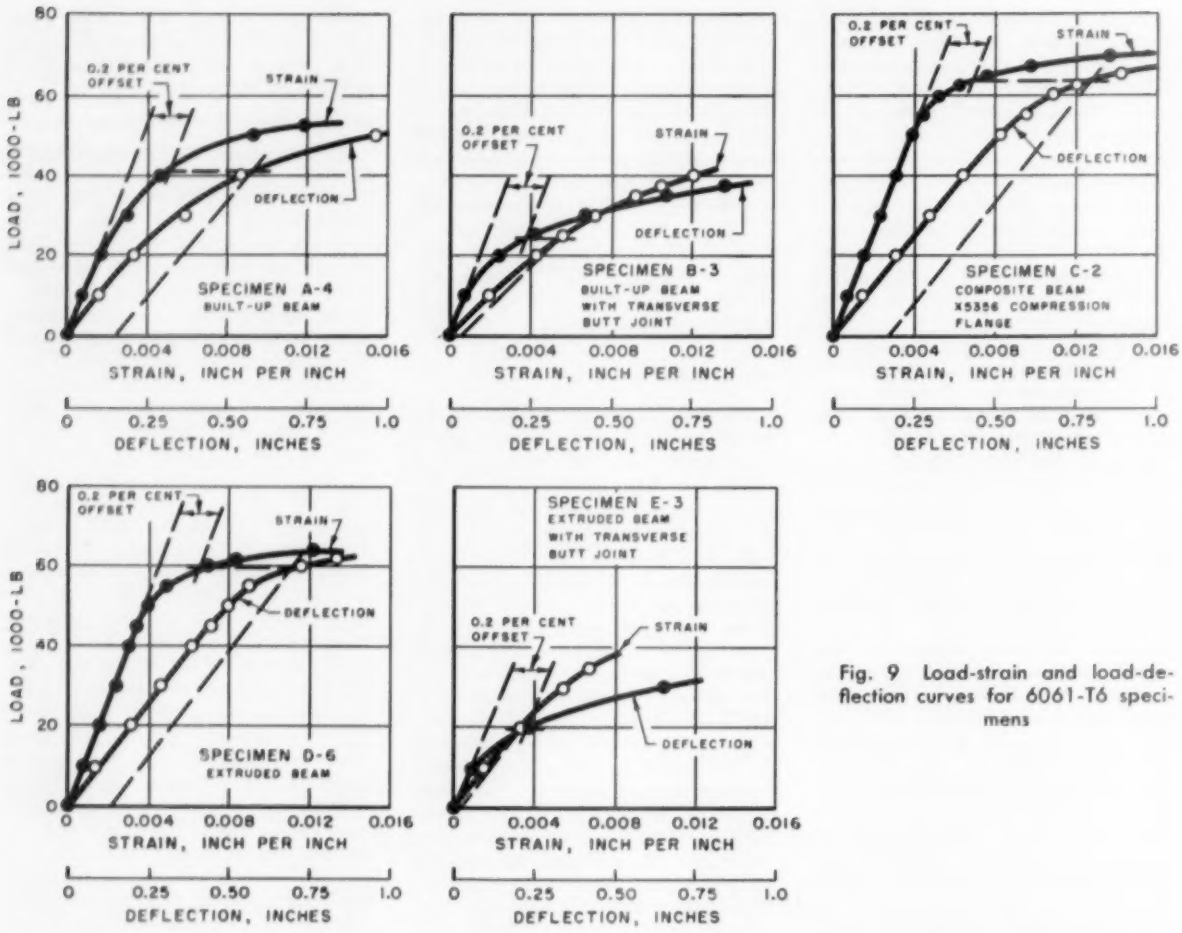


Fig. 9 Load-strain and load-deflection curves for 6061-T6 specimens

On the basis of offset deflection, the specimens can be placed into two groups; those which are continuous without a transverse joint and those with a transverse joint. For the beams without transverse joints (A4, C2 and D6), the offset deflections are about 0.2% of the span; whereas, for the beams with joints (B3 and E3), the offset deflections are about 0.033% of the span. It would appear from this that one definition and criterion for beam yield strength will not fit all cases.

For the extruded beams in each alloy, the departures of the load-deflection curves from the initial straight lines occur at loads corresponding to computed stresses approximately equal to the yield strengths.

V. Concluding Remarks

The foregoing data and discussion indicate that satisfactory welded structures can be made from these three aluminum alloys. The strengths of welded joints in cold-rolled or heat-treated plates are less than the tensile strength of the parent plate but greater than the strength of the material in the annealed condition. Beams built up from material in the harder tempers with longitudinal welds have strengths significantly greater than those of annealed beams. On the other hand, the strengths of the beams with transverse joints are dependent on the strength of the welded joint. Because of the greater strength of welded joints in the non-heat-treatable alloys, transversely jointed beams of these alloys are stronger than are transversely jointed beams of the heat-treatable alloy.

Acknowledgment

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THE WELDING OF COPPER AND ITS ALLOYS

Review of the literature published from 1936 to 1954 includes the optimum procedure to solder, braze or weld any of the copper alloys

BY IRA T. HOOK

FOREWORD. In the earlier review terminating on Jan. 1, 1936,[6] an attempt was made (1) to summarize the knowledge of the art of welding copper and copper alloys in order to avoid duplication of effort in planning researches and (2) to enable one to plan the optimum welding method for a given alloy or a given connection. At that time, there was much confusion as to the efficacy of (1) various additions to the base metals, (2) to the filler rods, (3) to the fluxes and welding rod coatings, (4) of the various gases involved in welding and (5) of the various welding methods themselves.

There were questions as to the desirability of a long arc or a short arc; of alternating current or direct current; of straight polarity or reversed polarity.

In resistance welding, questions were unsettled as to flash heating or straight resistance heating; time and temperature of heating; and push-up speed and pressure. Radically different changes in the design of welding equipment were still to be tried.

Welding was an art still in the adolescent stage though it had its roots far back at the beginning of the Christian era. It probably started with the blacksmith's welds in the ferrous metals and in the flow brazes in bronze and fused joints in lead of the Romans. Beginning about 1905 in Europe and in this country, welding took an accelerated pace forward with the advent of the oxy-acetylene welding torch, the oxygen cutting torch, the carbon arc, the metal arc and the resistance butt and spot welder.

By 1936, nearly all of the welding processes now in use were known but many were unsatisfactory in specific applications because of lack of refinements or because of unknown factors. Many of these factors have been evaluated in the past 18 years. There are few applications at this time for which a satisfactory method of joining is not available. This is not saying that the welding art has solved all its problems. Much remains to be done.

What we have been witnessing in the past two or three decades has been the rapid metamorphosis of the art of welding into the science* of the joining of metals and plastics. This science is still in the development stage. A great deal of welding is done in which the skill of the welder plays an important part in the procedure. In the making of many other welds, the variables have been placed under automatic controls enabling one to predict the properties of the finished weld—and specifically, enabling an inexperienced operator to make satisfactory welds in part of a manufacturing process.

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Table 1—Joining Processes and Temperature Ranges

Joining process	*Temperature range* — *Minimum*	*Maximum*
Cold welding	Room temperature or above	
Soft soldering	183° C (361° F)	240° C (460° F)
Silver brazing, hard soldering	635° C (1175° F)	843° C (1550° F)
Brazing, braze welding	871° C (1600° F)	954° C (1750° F)
Copper-hydrogen brazing	1094° C (2000° F)	1149° C (2100° F)
Fusion welding, resistance welding	885° C (1625° F)	1261° C (2300° F)

This review has for its primary aim the summarizing of information published since 1936, which will enable one to find the optimum procedure to solder, braze or weld any of the copper alloys.

One thing that makes it unnecessary to extend it greatly is that, in the intervening years, handbooks[2-4] have been published containing a wealth of accredited information on welding.

In addition, most welding products manufacturers and welding equipment manufacturers have published useful, instructional brochures on welding, as the art relates to their particular metal or equipment. These last will not be reviewed herein since an inquiry may be sent directly to such manufacturers.

Plan of the Review

Since the purpose of the review is to draw attention to the most satisfactory procedures for welding copper alloys, the review will ignore for the most part the enormous volume of literature dealing with the ferrous metals and with aluminum, magnesium, titanium and other metals not commonly associated with copper and the copper alloys. Owing to time limitations, the review will also have to ignore the very important contributions in the French, German and Russian languages.

In order to make the review useful—make it understandable to those who are called upon to design joints in copper alloys or to actually make the connections therein—the review will deal: (1) with the metallurgy of the copper alloys as it affects the quality of the weld, and (2) with the effect of various joining methods, pointing out those which have been most satisfactory over the years.

In this connection, the review should also point out those metallurgical constituents and practices which are detrimental to weld quality and those welding methods which are inappropriate to a given copper alloy.

In discussing (2) above i.e., joining processes for copper alloys, the review will follow commercial practice and group them in the broad classification in which they are used. The temperature scale will be taken as the primary coordinate with the various distinctive joining processes dependent thereon, Table 1.

Table 1 is a much abbreviated statement of the WELDING HANDBOOK's chart of welding processes[2] on its page xii. Three of the eight general welding processes, i.e., Forge Welding, Thermit Welding, and Flow Welding are not included in Table 1 above. The reasons for these omissions are stated below.

Forge welding which has been so successful in the familiar blacksmith's welds on wrought iron and steel since the beginning of the Christian era has never been successful with copper, brass or bronze. The oxides formed on the

* An art has been defined recently[1] as "The reduction of a complex of ideas to a form that appeals directly to the emotions of man." This is a true but somewhat clumsy definition. An art arrives, by the trial and error method, at an objective or procedure which appeals to man's sense of the fitness of things.

A science, on the other hand, is an organized body of knowledge which enables one to explain a phenomenon or predict an effect from an application of the underlying laws which govern. These laws may have been discovered in studying the facts accumulated in the development of an art.

copper alloys are more closely clinging and interfering than the oxides on the ferrous metals. Theoretically speaking, it should be possible to dissolve the copper oxide films with borax and then effect a hammer weld at about 1200° F but, practically, it is not easy. It has never been an acceptable process.

Flow welding was used by the Romans in the manufacture of bronze bathtubs, in which process the edges of the adjoining parts were brought to the fusion welding temperature by flowing molten bronze over them and using part of same for the filler metal. Flow welding is sometimes used in the brass foundry to fill out a worn, broken or imperfect casting, as a ship's propeller. In this case, the casting is heated and the place to be filled set on a slope. Superheated metal of the same composition, manganese bronze perhaps, is flowed over the base metal until the area is brought to temperature and cooler filler metal allowed to solidify. With modern facile control of heat in the torch or arc, flow welding need be given no further consideration.

It will be noted in Table 1 that there are both gaps and overlappings in the temperature scale. That is actually the way it is in commercial practice. The most serious gap is that between soft soldering and silver brazing. There is an unsatisfied demand for a medium-hard solder in this range, i.e., 460 to 1175° F. Actually, there are alloys to meet it, as will be pointed out later. But, at the moment, there is no flux that is entirely dependable in this temperature range. The aluminum industry has silver alloys and fluxes that melt around 1000° F, but these have not been used on the copper alloys. This temperature gap is not as bad as the temperature range makes it appear for the reason that torch equipment used in soft soldering can be employed with equal facility in silver brazing.

Again, the temperature gap between the silver solders, phosphorus-coppers and the brazing alloys is more apparent than real. With proper design of the connection, either silver brazing or brazing may be used.

Copper-hydrogen brazing is in a different category from brazing and braze welding as will be seen later. The overlapping between this process and fusion welding will also be explained.

Elements Associated with Copper

In Table 2, the various elements associated with copper in making the thousand and one copper alloys are listed. The melting and boiling points are given for each element, together with the proportional range in which it is added to copper.

The melting and solidifying temperatures of a given element are always at a common, definite value, characteristic of the given element. The melting and solidifying temperatures of an alloy are usually not the same. In the temperature range between the liquidus and the solidus of an alloy, the material will be a mixture of liquid and solid particles.

There are several important exceptions to this last stated rule. A few binary alloys have a definite, common melting and solidifying temperature known as the eutectic temperature.

Table 2—Elementary Metals Associated with Copper in the Copper Alloys

Element	*Melting point, ° C (° F)*	*Boiling point, ° C (° F)*	*Proportions used in a copper alloy, %*			*Alloy type*
			Min	*Max*		
				Wrought alloy	*Cast alloy*	
Aluminum	600 (1220)	2060 (3740)	0.00	11.00	11.00	Aluminum bronze
Arsenic*	615† (1139)†	...	0.00	1.00	...	Arsenical copper
Beryllium	1280± (2340)	2770 (5020)	0.00	2.25	2.75	Beryllium copper
Boron	2300 (4200)	2550 (4620)	0.00	0.05	...	
Cadmium	321 (610)	765 (1409)	0.00	1.00	...	Cadmium copper
Chromium	1890 (3430)	2500 (4500)	0.00	1.25	1.25	Chromium copper
Copper	1083 (1981)	2600 (4700)	55.0	100.00	100.00	Electrical copper
Iron	1539 (2802)	2740 (4960)	0.00	3.00	5.00	In aluminum bronze and manganese bronze
Lead	327 (621)	1740 (3160)	0.00	3.50	30.00	Leaded copper, brass and bronze
Magnesium	650 (1202)	1110 (2030)	0.00	0.05	...	As deoxidizer only
Manganese	1245 (2273)	2150 (3900)	0.00	5.00	...	Manganese copper Manganese bronze
Nickel	1455 (2651)	2730 (4950)	0.00	30.0	30.00	Cupro-nickel and nickel-silver
Oxygen*	−219 (−362)	−183 (−297)	0.00	0.07	0.10	In tough pitch copper, electrical
Phosphorus*	44 (111)	280 (536)	0.00	0.50	5.0	Phos. deox. copper phos. copper, phos. bronze
Silicon	1430 (2605)	2300 (4200)	0.00	4.00	4.50	Silicon copper
Silver	961 (1761)	2210 (4010)	0.00	1.50	...	Silver-bearing copper
Tellurium	450 (840)	1390 (2530)	0.00	0.75	...	Tellurium copper
Tin	232 (449)	2270 (4120)	0.00	11.00	30.0	Bronze
Zinc	419 (787)	906 (1663)	0.00	42.00	50.0	Brass

* Usually regarded as a nonmetal.
† Sublimes.

At the same time, the definite proportions of the two elements are known as the eutectic proportions. The eutectic temperature is generally lower than the melting point of either constituent elementary metal.

The Metals Handbook[3] shows several important eutectic compositions of interest to the users of copper and copper alloys, thus:

1. The eutectic formed by the alloying of 28.1% copper with 71.9% silver melts and solidifies sharply at 779.4° C (1465° F).

2. Copper 91.62% plus phosphorus 8.38% has a eutectic temperature of 714° C (1317° F). In this case the eutectic temperature is higher than the melting point of the elementary phosphorus.

3. A brass made up of 62% copper and 38% zinc melts and solidifies sharply at 903° C (1659° F).

4. The important "tinners" solder is made up of 61.9% tin and 38.1% lead melting and solidifying sharply at 183° C (361° F). The more familiar 50:50 tin-lead solder has liquidus-solidus range 215° C (419° F)–183° C (361° F).

The boiling points of the elements are not as well authenticated as the melting points but are given for comparison. In only three of the elements, viz., cadmium, phosphorus and zinc are the boiling points of particular interests to the welder.

Table 2 is, for the sake of completeness, expanded from that given in the WELDING HANDBOOK,[2] p. 117, to include the minor as well as the major additions to copper to make commercial copper alloys. A few elements, such as tungsten, added to copper in the form of metal powders, compressed and sintered, are excluded.

Samans[71] remarks: "In general, the purer a metal is, the lower will be its hardness, alloys tending to be not only inherently harder than the metals upon which they are based, but also more susceptible to changes in hardness caused by mechanical work or heat treatment."

The amount of the addition of some elements to copper is sometimes greater for a casting than for a wrought metal. This fact is of interest to the welder, as many times he is called upon to make harder weld deposits than are obtainable from a wrought alloy filler rod. He accomplishes this by using cast rods or he uses composite rods or metal powders in the coatings.

Grouping the Copper Alloys

Copper and the various copper alloys may be assembled into a comparatively small number of groups, each of which has, respectively, some similarity in the reaction of the individual alloys to welding metallurgy. The many hundreds of copper alloys[9] in general use are summarized in Metals Handbook,[3] pp. 903 to 942, into 65 representative alloys with metallurgical and physical properties given in detail for each, together with the ASM, the ASTM, Federal or other specifications which apply. The ASME in its Handbook on Metal Properties[5] likewise reports the physical, technological and mechanical properties of 65 representative copper alloys, though these are not in every case identical with those in the former handbook.

H. J. Miller[8] published, for the benefit of the British copper industry, an excellent summary of copper alloys in 17 tables or groups. He included compositions, properties and appropriate applications. He mentioned welding.

None of the above lists of copper alloys are, on account of their length, given here. A student of copper welding should, however, be familiar with such detailed alloys and their properties.

The WELDING HANDBOOK[2] lists eight groups of copper alloys with 27 representative alloys incoporated therein, with details of chemical, physical and welding properties given.

J. Imperati and the writer grouped the many copper alloys into eight divisions[7] as shown in the first eight groups of Table 3. Groups 9 and 10 have been added to this table for the sake of completeness.

In this review, the classification of Table 3 will be used. The properties of these ten groups, as the properties are related to welding, will be explained. Among the thousand and one copper alloys,[9] there will be some which will not have a composition falling within the limitations of Table 3. However, notes on the metallurgy of the elements of Table 2 will usually provide a clue as to the group into which any specific alloy may be placed.

Table 3—Copper Alloys Grouped According to Welding Characteristics

Group No.	*Composition, %*	*Name, remarks, and ASTM specifications*
1	99.9+ copper	(*a*) Tough pitch copper. Carries 0.02 to 0.07% of oxygen in form of microscopically small specks of cuprous oxide. ASTM B152, Type ETP and FRTP. (*b*) Deoxidized or oxygen-free copper. Has no cuprous oxide in it. Phosphorous deoxidized copper has 0.015 to 0.040% residual phosphorus. ASTM B152, Type DHP.
2	95 to 80 copper 5 to 20 zinc	Commercial bronze and red brass. Special alloys may contain lead for free machining or tin for improved strength and resilience. ASTM B36.
3	75 to 58 copper 25 to 42 zinc 0 to 1 tin	Spring brass, cartridge brass, common brass, Muntz metal. An addition of 0.5 to 1.0% tin is found in Tobin Bronze and Admiralty. Also fractional percents of tin, iron and manganese in manganese bronze. 2 to 3% of lead is generally found in extruded architectural bronze and brass forgings. ASTM B36 and Navy 46B6.
4	72 to 55 copper 10 to 32 zinc 10 to 20 nickel	Wrought nickel silver usually has 18 to 25% nickel with 20 to 25% zinc. Extruded nickel silver is higher in zinc, about 40% and lower in nickel, 10 to 12% with 2 to 3% lead. ASTM B122.
5	90 to 70 copper 10 to 30 nickel	Cupro nickels. ASTM B122 and Navy 46C6.
6	96.5 to 89 copper 3.5 to 11 tin 0.03 to 0.35 phos.	Tin bronze or phosphor bronze. Grade A phosphor bronze has 4 to 5% tin, Grade C about 8% tin, and Grade D about 10.5% tin. ASTM B103.
7	98 to 95 copper 1.5 to 3.5 silicon 0.50 to 1.5 manganese, zinc or tin	Copper-silicon alloys. ASTM B96.
8	96 to 88 copper 4 to 9.0 aluminum 0 to 3.5 iron	Aluminum bronze, forging bronze and Avialite bronze. Frequently contains about 1% of iron, manganese and/or nickel. ASTM B169.
9	97.40 to 98 copper 0.25 to 0.50 cobalt or nickel 2.00 to 2.25 beryllium	Beryllium copper. Precipitation hardenable[3] (p. 934).
	99.0 copper 0.8 to 1.0 chromium 0.0 to 0.10 silicon	Chromium copper. Precipitation hardenable.
10	99.0 copper 1.0 cadmium	Cadmium copper. Used for electrical conductors having good strength.

Welding Metallurgy of Copper and the Copper Alloys

In a fusion weld, the metal has to run the gamut from room temperature through preheat to melting, through solidification, possible hot working, and back to room temperature. The metal expands and contracts, bringing into play strength and ductility, hot and cold. These are effects which are of as much interest to the welder as to the metallurgist.

Specific properties of interest to the welder in the metals of a weld are: (1) Surface conditions of the solidus, (2) of the liquidus, (3) thermal conductivity, (4) melting point, (5) boiling point, (6) cold ductility, (7) hot ductility, (8) hot and cold strength, (9) coefficient of expansion and contraction, (10) reactions with air, welding gases including heating and shielding gases, (11) reactions with the fluxes, fluxcoating and finally (12) the soundness, ductility, hardness and strength of the finished weld.

However, rather than discuss these properties categorically, attention will be called to them as the joining process itself is described.

Optimum Joining Processes for the Copper Alloys—An Evaluation

The six processes listed in Table 1 are discussed in proper sequence below. Note that the *sequence is arranged in order of temperature from room temperature to that of the liquidus of the most refractory copper alloy at about 1260° C (2300° F).* Any of these temperatures are readily attained by modern welding equipments, furnaces and induction heaters.

Aside from such strictly mechanical connections as riveting, bolting, threading, clamping, wrapping of wire, seaming of sheet metal, etc., we have numerous variations of joining in which the atomic bond is brought into play. These are the connections with which we are concerned here. Table 1 shows the various joining methods which are applicable, together with the temperature range to which the base metal and the filler metal are heated.

Cold Welding

The metallic (atom) bond is a powerful force of extremely short range of the order of perhaps less than 10 A units center to center of atoms. Glasstone[10] remarks "that metals are characterized by the presence of a special type of metallic bond, in which a relatively small number of electrons are able, *in some manner*, to bind together a large number of atoms or, more correctly, ions."

The metallic bond is progressively weakened as the atom energy is increased with the temperature until at the melting point, and up to the boiling point, the gravitational force on the atom supersedes the metallic bond.

Cold welding contemplates forcing atom pairs, one from each of the metals to be joined, sufficiently close by mechanical pressure to bring the metallic bond force into play. If a sufficient number of atom pairs are brought together across the joint, a more or less strong weld will be obtained—and the strength partly retained after the external pressure is relieved.

A molded part made of powdered metals compacted under the normal commercial pressure is a case in point.[3] The part will endure reasonable handling because of the atom bonds at pressure points between powder particles. But in few cases is the integrity of the molded part sufficient for its intended use. It must be handled gently. Only after sintering is its strength and hardness sufficient for its intended use.

Sintering temperatures for copper alloys are given in Metals Handbook[3] as 1300 to 1650° F. Such temperatures are far above the recrystallization temperature and approach incipient fusion. They undoubtedly promote mutual diffusion of the materials of the faying surfaces.

Wulff[14] remarks, "The cohesive strength of the material (powdered metal) depends on . . . . . the atomic bonding between contacting surfaces. The greater the plasticity of the powder, the greater the probability of forming such bonds."

The principal difficulty in establishing the metallic bond in making cold (room temperature) welds, seems to be the elimination of surface films from the faying surfaces. Sowter,[13] in describing the process for aluminum, says that after cleaning the surfaces of all grease and dirt, which may be accomplished by the usual mechanical or chemical methods, the clean metallic surface must be further reduced to raw metal by scratch brushing preferably by a high-speed revolving wire brush having suitable steel wires as to size and hardness. Chemical cleaning is unsatisfactory as the chemical must be washed off, which washing invariably leaves an interfering film.

The second requisite according to Sowter[13] is a pressure (at room temperature) sufficient to deform the metal. In the case of aluminum this is stated to be 24,000 to 36,000 psi, while for copper it should be two to four times this value. Dubillier[15] agrees that pressures for aluminum should be 27,000 to 40,000 psi, with 2 to 4 times these values for copper.

Parks[16] in an exhaustive study of the spot welding of copper and brass at recrystallizing temperatures used a different approach from Sowter by (1) using cold worked surfaces, (2) lighter pressures and lighter deformations and (3) temperatures elevated to those causing recrystallization. He also used circular spot welds which were objected to by Sowter as restricting flow of the metal under pressure in a manner to destroy the cold welded bond.

However, Parks[16] proved that excellent solid-phase spot welds were obtained in electrolytic copper when the spot welds were made at temperatures between 300 and 400° F, and in cartridge brass at temperatures from 500 to 800° F. The welding process (bonding time) was 15 min for the copper and 2 min for the brass. He relates the recrystallizing temperature, degree of deformation and recrystallizing time (time at welding pressure) finding this last variable to be from 10 sec to 10 min.

Kinzel,[17] whose work was done in 1944 several years before cold welding was announced, contemplates another type of solid-phase welding from the cold welding described by Sowter and Dubillier and the recrystallizing welding investigated by Parks. He uses carefully prepared surfaces, held together at a definite pressure and heated at the interfaces and back of the interfaces to a forging temperature. The pressure is insufficient to cause deformation at room temperature but high enough to deform the heated, but still solid, metal.

Kinzel agrees that physical tests of the solid-phase weld provide an indication of the quality of the weld, but he also insists that the interfaces should be obliterated (1) by crystal growth across same and (2) by diffusion of any nonmetallic film, such as an oxide, which may have been present at the interface.

Most of his work was done upon steel but experiments with copper, 70/30 brass and 60/40 brass indicated that solid-phase welds were possible at temperatures approaching, but well below, the solidus temperature. Kinzel remarks that "Copper can be welded at temperatures close to the melting point only with great difficulty." The 60/40 brass, which has an alpha-beta transformation at temperatures around 1400° F, welds at a lower temperature than copper or the 70/30 brass which have no such transformation. Kinzel postulates that the diffusion of atoms and nonmetallic solute molecules is accelerated by such transformation.

Davis and Holmes,[18] having the advantage of the foregoing reports, made in 1949 a more thorough investigation of the characteristics of copper alloys in solid-phase, elevated-temperature welding. Tests were made on phosphorus deoxidized copper, 70/30 and 80/20 cupro nickels; 93/7 and 91/9 phosphor bronzes; 85/15 red brass, leaded brass alpha-beta brasses, silicon bronze and aluminum bronze.

Temperatures varied from a low of 475° C for one test on leaded brass to

1200° C for one test on cupro nickel. Heat was furnished by an oxy-acetylene ring burner of 6 nozzles which also flooded the contacting surfaces throughout the welding operation. Time varied from 15 sec to 10 min.

Deformation was determined as the per cent increase in the area of the contacting faces in terms of the final area.

Davis and Holmes were able to get satisfactory welds on all copper alloys except the aluminum bronze which had a somewhat erratic performance due to aluminum oxide in the connection.

They found that the deformation was the most critical variable, the welded strength being a maximum with deformations as high as 80%. Deoxidized copper was an exception with deformations as low as 6 to 12% resulting in full annealed strength across the weld.

Conclusions as to Solid Phase Welds

It seems to the reviewer that solid-phase welds can be made in copper and copper alloys provided the conditions are correctly adjusted for each alloy.

The attainment of these conditions may be impractical when the cost is compared to that of a fusion weld.

The state of the art is silent on one important point—protection of the clean contact surfaces during the heating-up period. The burnt gas from the oxy-acetylene torches used by Kinzel and by Davis and Holmes gave a measure of protection from the oxygen of the air, but the water vapor inherent in such burnt gas will oxidize many of the copper alloys if the temperature is sufficiently high.

The protection needed may possibly be supplied (1) by a suitable flux, (2) by an inert dry gas as helium or argon or (3) by a noble metal film. We have found no reference in the literature to any of these methods. The flux method offers little success, as the fluxes which are satisfactory at temperatures up to 500° F are unsuitable at higher temperatures, and those good for the 1100 to 1700° F range offer no protection at lower temperatures. A mixed flux is still possible but is not known at present.

The noble-metal film need not be a metal of the gold or platinum group, though these are particularly inert to oxygen at all temperatures. Silver, tin and iron are possibilities still to be tried. Iron, for example, is used in this manner in the manufacture of stainless-clad carbon steel.[7] In this case, steel alloy plates are coated with a few mils of pure iron and hot rolled together. Grimshaw[8] describes the method in detail.

Of the other variables involved in solid-phase welding as (*a*) pressure, (*b*) deformation, (*c*) temperature and (*d*) time, the pressure appears to be a means to an end only. It must be high enough to cause a critical deformation. The deformation in which the metal in the contact plane will stretch seems to be fundamental. In other words, the surface film of the contact surfaces must be pulled apart. But this is always accomplished indirectly—much as Poisson's ratio effect is attained by elastic stresses.

The pressure on the surfaces causes a sidewise expansion. Sowter shows that a restraint of this sidewise expansion (as in a spot weld made in a large area) reduced the strength of the weld over that made at the edges of the same sheets where the restraint to sidewise slip is reduced on one side.

A pressure sufficient to cause the desired deformation at room temperature is easily attained in spot and seam welding of soft sheet metals, *i.e.*, pure aluminum and soft metals. It is more difficult with copper and the copper alloys, though by mechanical or hydraulic pressure it is still possible.

In butt welding of sheet metal, rods, bars, shapes and tubes, the means of attaining the desired deformations are more difficult. And the expense may be prohibitive when the materials are kept at room temperature.

For this reason, it may be desirable to raise the temperature, which in turn will reduce the yield point of the copper alloy and allow the desired deformation to take place at moderate pressures and times.

The elevated temperature accomplishes two other desirable conditions, it makes the atoms more active and improves the diffusion of film components into the metal. Whether the temperature needs to be above the recrystallizing temperature or not seems to be an open question though, undoubtedly, a high temperature promotes grain growth across the contact plane.

Soft Soldering

Temperature 360—470° F*

Soft soldering of the copper alloys of Table 3 in the case of all of the ten groups except Groups 7, 8 and 9 is so simple and so universally used as to need little explanation. The WELDING HANDBOOK[2] disposes of the subject for all base metals in 2½ pages. The Metals Handbook[3] deals with the subject at somewhat greater length. Perhaps the most complete study of soft soldering is that published by R. M. MacIntosh in THE WELDING JOURNAL.[12]

MacIntosh remarks,[12] "The process of soldering is relatively simple, but it requires considerable skill and ingenuity to produce a joint of optimum properties. A thorough knowledge of the fundamental properties of solder alloys and methods of applying them is needed in order to use solder efficiently at modern production speeds." This is undoubtedly true. Many inefficient joints are made. In some cases, this is due to the lack of skill of the operator, and in others, to his insufficient knowledge of the factors involved in soft soldering.

Typical soft solders are given in ASTM Specifications B32-49.[19] Of the 30 soft solders listed, the following are typical of those most commonly used with copper alloys.

The first three solders of Table 4 are taken from the above specification. The 95 tin–5 antimony solder is quoted by MacIntosh from the U. S. Federal Specification QQ-S-571b. He also shows the two silver-lead and silver-cadmium solders.[12]

The 60 tin–40 lead solder is useful in a variety of applications on copper and copper-alloy sheets and wires where quick solidification is desired. The 50 tin–50 lead solder is preferred for soldering soft and cornice temper copper roofing sheets and for leader and gutter work. The higher tin content of the former is preferred for cold-rolled copper, brass, and bronze sheet and strip and cold-drawn copper and bronze wires. The 50:50 solder is commonly used for sweat soldering of copper plumbing installations, but it should never be used where the connection is subjected to a stress as in a long riser for a tall building.

The 95 tin–5 antimony solder is preferred for hot water plumbing and for heating installations because of its better strength at elevated temperatures up to 215° F.

The last two solders listed in Table 4 are intended for applications where service temperatures are apt to go above 215° F. They are not as easy to apply as the lower melting solders, but the difficulty lies more with the fluxes than with the solders or the heating torches. The chloride fluxes break down at temperatures under 600° F, exposing the surfaces to the torch gases or the air.

Referring to Table 3, all of the copper alloys except those of Groups 7, 8 and 9 are easily soft soldered. The copper-silicon alloys of Group 7 are soft soldered without difficulty provided the metal is cleaned and fluxed before being heated.

Hard copper, hardened by cold rolling of sheet and strip or cold drawing of tubes, wires, bars and shapes, will usually retain the cold-work hardness through a soft soldering operation as they will not in a brazing or fusion welding operation. However, pure copper with a softening point about 200° C (392° F) is sometimes softened

* Less frequently and with more difficulty, due to flux limitations, medium temperature solders are applied at temperatures between 360 and 750° F.

Table 4—Typical Soft Solders

Nominal composition, %		Melting ranges		
Tin	Lead	Solidus	Liquidus	Applications, remarks
60	40	183° C (361° F)	190° C (374° F)	Tinners solder, quick solidification. Used on thin sheet copper and brass.
50	50	183° C (361° F)	216° C (421° F)	General purposes. Most popular of all for copper alloys.
40	60	183° C (361° F)	238° C (460° F)	Plumbers wiping solder. Not commonly used on copper alloys.
95	5 Sb	233° C (452° F)	240° C (464° F)	Antimonial tin solder. Stronger joints for hot water lines than the 50:50 solder.
2.5 Ag	97.5 Pb	304° C (579° F)	304° C (579° F)	High temperature, soft solder. Torch soldering.
5 Ag	95 Cd	340° C (644° F)	400° C (752° F)	High temperature, soft solder. Torch soldering. Good corrosion resistance.

unduly in a soft soldering operation, as in the manufacture of automobile radiator cores, for example. In such cases, copper, with an addition of 0.03 to 0.10% silver, or a red brass, is preferred.

The aluminum bronzes and beryllium coppers of Groups 8 and 9 are difficult to soft solder. Silver brazing is a preferred method of joining. Richards[20] suggests that beryllium copper should be soft soldered only when the stress on the connection is low.

Solders are available in a wide variety of bars, wires, cored wires and powders. G. H. Bohn[22] gives an excellent discussion of the variables involved in soft soldering the copper alloys as (1) the solders and their properties, (2) heating methods and types of flames, (3) fluxes, (4) design of joint to be soldered, (5) copper and brass base metals, etc. Bohn recommends a careful study of the Bureau of Standards publications on solders and soldering.[23]

Fluxes for soft solders are obtainable in a wide variety. MacIntosh[12] lists seven general types of inorganic fluxes and 14 organic fluxes. There are many more proprietary fluxes.

Rosin is the flux most commonly used when a noncorrosive one is desired, as on electrical equipment. Proprietary varieties of noncorrosive fluxes are available in powder, liquid, solder-cores and mixed with powdered solder.

Silver Brazing, Phosphor Copper Brazing

Silver Brazing or Hard Soldering, 635° C (1175° F)–843° C (1550° F)

All of the copper alloys in the ten groups of Table 3 are brazed more or less readily by the alloys in the silver solder group.[19] Some typical silver and other hard solders are listed in Table 5. The first three are from the ASTM Specification B73-29,[19] while the other three are reported in the WELDING HANDBOOK,[2] p. 866.

The use of a silver brazing alloy on copper and the copper alloys results in a ductile, high-strength, corrosion-resisting connection. The heat used in making the connection will usually anneal the copper alloy in the joint though, in some alloys, part of the cold work strength and hardness may be retained. The speed with which the silver soldering is accomplished determines the amount of cold work hardness and strength retained in the finished braze. The precipitation hardening alloys of Group 9 are treated separately later.

Nearly every form of heating, except the arc, is used on one job or another to melt the silver alloy and heat the base metal.

There are numerous references in the literature to brazing with the silver alloys and phosphorus copper alloys of which the following are typical.

Van Nattan[40] writes a very complete discussion of base metals, appropriate brazing solders, heating methods, fluxes, connection designs and appropriate application. Copper alloys are indicated as base metals and brazing solders. Wirt[41] gives a survey of brazing at Delco-Remy Division of General Motors Co. The American Welding Society Committee[42] gives compositions of 32 brazing metals suitable for the joining of most commercial engineering and noble base metals. Data on available forms and brazing temperatures are quoted.

Kriegel[39] discusses the use of the BAg-1a silver solder on various designs of joints in copper, Everdur, Monel and other copper alloys.

Weir and Webber[22] report the silver brazing of 1237 (3/4 OD x 0.049-in. wall) deoxidized copper tubes into 48-in. diam by 3/8-in. thick steel tube sheets to make a 225 psi steam heating boiler good for an evaporation of 6800 lb per hour. The brazing alloy was the BAg-1a in Table 5 above. The brazing operation eliminated a mechanically rolled connection using steel ferrules. The brazing provided ample strength in the bond between the dissimilar metals and eliminated much of the maintenance trouble.

C. C. Natebaret[23] used powdered silver solder mixed with flux and the clamped edges heated with an oxy-acetylene torch. Mesh of extremely fine wires woven 76 per inch was successfully joined.

R. J. Wensley[24] reports the use of carbon-resistor jaws electrically heated to clamp the copper switch parts and heat same until the preplaced silver solder melts. This method was satisfactory with brass, bronze and steel, but difficulty was experienced with leaded brass due to the sweating out of the lead, and with aluminum bronze due to the film of aluminum oxide on same which is difficult to flux.

R. H. Leach[25] contributes general discussion of silver brazing alloys and procedures with a brief survey of the literature. C. F. Zappone[26] gives an excellent summary of the methods used in silver solder brazing current in 1940.

R. L. Briggs[27] explains a method of silver brazing by resistance heat pulses which work so rapidly that the hard copper is not appreciably softened.

Table 5—Typical Silver and Hard Solders

Grade	Composition, % Silver	Copper	Zinc	Cadmium	Solidus	Liquidus	Remarks
1	10	52	38	...	820° C (1510° F)	870° C (1600° F)	For silver brazing steel, etc.
5	50	34	16	...	695° C (1280° F)	775° C (1425° F)	For general silver brazing.
8	80	16	4	...	740° C (1360° F)	795° C (1460° F)	For silver brazing copper.
BAg-1a	50	15.5	16.5	18	627° C (1160° F)	635° C (1175° F)	For general low temperature silver brazing.
			Phosphorus				
BCuP-5	15	80	...	5	640° C (1185° F)	785° C (1445° F)	For brazing copper only.
BCuP-4	...	93	...	7	743° C (1370° F)	788° C (1450° F)	For brazing copper only.

C. M. Robins[28] reports the widespread application of silver brazing to war equipment manufacture, as 400 brazed parts in an airplane and several hundred in a single torpedo, with eight miles of silver-brazed piping on a ship and nearly all tungsten-carbide tools silver brazed to the shank.

G. H. Bohn[30] discusses the proper design of joint for silver brazing sheet, tubes and thick shells.

H. A. Smith and P. A. Koerner[31] analyze design factors, procedures, operator qualification, etc. They relate same to strength of silver brazed joint in steel obtaining an average shear strength in the solder of 43,200 psi in joints designed for 35,000 psi. They prefer the oxy-acetylene or the induction method of heating.

Christie and Setapen[34] discuss the inspection and testing of silver brazed joints, directing attention to requirements for standard test procedure. Consideration is given to such variables as (1) type of joint as butt, scarf, lap, (2) design of complete connection, (3) surface considerations, (4) jigging, (5) fluxing, (6) proof tests, (7) brazing controls, (8) tests after brazing, as visual, mechanical, pressure, metallographic, though no actual tests are quoted as was the case with Koerner's report.

J. P. Weed[29] describes an early application of silver brazing by the use of induction heating after trying other methods. An objection to induction heating is its high initial cost.

Bunte[37] gives a very complete resumé of induction heating methods for low- and high-temperature brazing in ferrous and nonferrous metals. The frequency of the heating current may be stepped up by (1) motor generator, (2) spark gap or (3) vacuum tube. Generators not yet available for 30 kc; spark gaps 80 to 525 kc; tubes 400 to 500 kc or above. Capacities of $7^1/_2$ kw in generators; spark gap up to 30 kw and electronic sets from 200 w to 100 kw in size. Benefits of induction heating are said to be (1) more heat in a given area with better control, (2) greater uniformity of results, (3) greater production for a given floor space, (4) maximum economy in mass production, (5) possible use of unskilled labor. The lone objection is the high first cost of the equipment in this new field.

Brazing by Induction Heating

J. P. Weed[29] and others give useful data. After the initial cost of induction heating equipment is absorbed, economies in its use are readily demonstrated. Gise and Stewart[35] show how it speeds up production in the manufacture of kitchen utensils. Using a 20 kw, 450 kc R-F generator for silver brazing 1500 sets of 6-piece kitchen utensils per 15-hr day, the cost is reduced from $390 for torch brazing to $162 for the induction method. Moreover, with the latter method, workmanlike connections are obtained with inexperienced operators while skilled operators are required for torch brazing. Vernor and Adams[36] tell a similar story in making a silver braze in 30 sec for tungsten carbide tips to steel shanks using 10 kw at 450 kc.

Speed-Up Methods

In addition to the use of induction heating for silver brazing, rotating tables and moving belts are in use for speeding production. Setapen[38] explains the use of a rotating table with fixed oxy-acetylene burners. Swarthout[39] cites the brazing of air-conditioning and refrigerator parts and copper tubes with the oxy-acetylene torch using both silver alloys and the yellow bronzes.

The *Welding Engineer*[43] reports the reduction of the brazing time from 4 min to 40 sec in a given job, with a uniformity in brazing such that inspection could be eliminated. The heat was obtained from an induction heater. Another report in the same magazine in August 1944 tells of cutting the time of a different brazing job from 7 to 12 min to 51 sec. Kielb[44] tells of using a gas torch in production—line brazing in preference to arc welding, while Scott[45] cites the use of brazing—in this case using a phosphorous copper brazing alloy—replacing soft soldering with economy and improved strength.

Johnson and Huff[47] discuss automatic torch brazing with standard oxy-acetylene torches and turntables or conveyor belts. They mention practical applications. Another article in the October 1950 issue of the *Welding Engineer* reports that turn-table brazing and induction heating were responsible for cutting one-third off the brazing costs in the manufacture of 500,000 door rollbacks.

Two unique methods of heating for brazing are reported in the *Welding Engineer*:[48] (1) the parts to be brazed inside a hydrogen bottle are heated to 1650° C by radiant heat and brazed, and (2) copper with preplaced brazing alloy is melted by resistance heat in molybdenum spot-welding electrodes.

Brazing Precipitation Hardenable Copper Alloys

The technique of brazing the alloys of Groups 7, 8 and 9 of Table 3 is no different from that employed in brazing the other seven groups of copper alloys. However, the cleaning of the surfaces and the fluxing of same must be done with greater care in order to forestall oxidation of the metal in the heating-up stage before the brazing flux or the brazing alloy melts and flows into place.

The fluxes made up of fused borax (with additions of a fluoride for the lower melting solders) mixed into a thin paste are usually satisfactory. Powdered brazing alloy mixed with the flux provides a coating of the solder the instant its melting point is reached. Once the faying surfaces are coated with the brazing alloy, the danger of oxidization is largely eliminated.

Setapen and Warren[50] report successful silver-alloy brazing of beryllium copper without seriously affecting age (precipitation) hardenability. Richards,[20] in a much more extended investigation, starts with a chemical cleaning of the metal using first 20% sulfuric acid at 150° F until black scale is off. Rinse, bright dip in 25% nitric acid 15 to 30 sec. Rinse in hot water and dry. Then clean mechanically immediately before fluxing for the brazing operation. Should use the BAg-1a solder or silver-copper eutectic alloy and braze as quickly as possible in order to retain a good share of the 600° F precipitation hardenability. Generally speaking, the brazing should be done *after* the solution heat and quench and *before* the precipitation hardening heat.

Brazing with Silver-Phosphorus-Copper and Phosphorus-Copper

These high phosphorus, copper-silver and copper alloys have their largest field of usefulness in the brazing of copper and the high copper brasses having 15% or less of zinc, Groups 1 and 2 only of Table 3 only.

One advantage in using these alloys is that the phosphorus in the brazing alloy will deoxidize copper on which it is melted, causing exceptionally good surface alloying with it. These phosphorus-bearing brazing alloys will not creep into the area between overlapping surfaces, as will either the soft solders or the silver solders (or indeed, the bronze brazing alloys). Hence, more attention must be given to the fillet at the edge of the braze than is necessary for soft solder or silver solder.

The phosphorus-copper brazing alloys have two further limitations which must be observed: (1) The brazing alloy should not be used on steel and (2) its low ductility rules it out of a joint that is subject to impact or bending stresses. With the above limitations considered, these alloys become valuable aids in joining copper.

Joining Copper Bus Bars

An unusually complete study was made by Goeller[51] on the brazing of 6- x $^1/_2$- in. bus bars assembled to carry 36,000 amp. An overlap of $1^1/_2$ in. with a sheet of 0.010-in. BCuP-4 alloy in the joint, clamped and heated with a torch, made perfect electrical contact and adequate strength.

Bessesen[52] used copper-phosphorus alloy in a rather unique manner in a braze butt weld with the carbon arc in

$^1/_4$- x 4-in. copper bus bars at the Wilson Dam. In four years' service, no trouble was experienced in heating of the joint, or in its mechanical strength.

The reviewer suggests that a copper welding rod with the inert-gas arc would make a more satisfactory butt joint. Falgner[53] gives a rather complete survey of the silver soldering of pipe, copper bus bars, tungsten carbide tools, etc.

A rather complimentary view of silver soldering was published by Clason[54] in describing the silver-brazed plumbing in the Lustron packaged homes. With a free choice to select any type of connection, the designers selected silver brazing as offering the most convenient, the strongest, most ductile, most corrosion-resisting joint available for copper tube plumbing installations.

Brazing

Brazing at Temperatures of 871° C (1600° F) to 954° C (1750° F).

The WELDING HANDBOOK[2] describes a braze as being the use of a nonferrous filler metal having a melting point above 427° C (800° F) on base metals having melting points well above that of the given filler metal. This definition includes silver brazing which has been treated separately above. We restrict the unmodified term "Brazing" to a much narrower temperature range following commercial practice in this respect. Braze welding, formerly called "Bronze Welding," is the use of the bronze filler metal in an open vee or fillet rather than its being drawn between overlapping surfaces by capillary attraction, as is soft solder and silver solder.

In this review, we take cognizance of practical classifications leaving gaps in the temperature scale which have little real meaning. For example, in using copper tubing for plumbing, the designer has a free choice as to whether he shall employ soft soldering, silver soldering, phosphorus copper or yellow bronze brazing. Each has its advantages and disadvantages, but the installation should give equally good service whichever process is used.

The WELDING HANDBOOK,[2] p. 512, gives a very complete listing of the brazing processes, the various filler metals with many compositions of same and appropriate base metals. This is too long to introduce here. Instead, the much shorter table of copper-alloy brazing metals given by Imperati[7] is reproduced in Table 6.

These braze welding rods are usable in most applications as hard solders which (1) will be drawn by capillary attraction into a joint which has overlapping surfaces, and (2) also as a filler metal in an open vee or as a fillet with ample strength to transfer stresses across the joint. The designer should take advantage of the distribution of the bronze in the joint as (1) above or (2) above or wherever possible, both as a hard solder and as a strong fillet or filler metal. Soft solders can rarely be used as in (2) above, because of their weakness to tensile stress. Silver solders are rarely used as in (2) above, because of the high cost, roughly 20 times that of the bronze, and because they are not as strong in direct tension.

Table 6—Representative Copper-Alloy Brazing Metals*

Mark or name	*Melting temp., ° C*	*Approx. compn., %*	*Remarks*
Spelter solders	882 (1620° F)	50 copper 50 zinc†	Yellow bronze in lump, granulated or finely powdered form.
Naval brass, Tobin Bronze, etc.	885 (1625° F)	57 copper 0.50 tin Remainder zinc	Free-flowing, yellow-bronze welding rod.
Manganese and low-fuming bronzes‡	871 (1600° F)	56 copper 0.85 tin plus iron, silicon, manganese Remainder zinc	Low-fuming, yellow-bronze welding rod, having high strength in braze welding.
Nickel bronze	921 (1690° F)	48 copper 10 nickel 0.10 silicon Trace of phosphorus Remainder zinc	Low-fuming, high-strength, white-bronze welding rod.

* Other copper alloys which melt at higher temperatures are also used for brazing, e.g., pure copper melting at 1981° F, and cupro-nickels at still higher temperatures. These, however, are used on ferrous metals and are unsuited for use on the copper-alloy base metals of Table 3.

† Part of the copper or zinc may be replaced by tin to reduce the melting point to 1495° F, or by nickel to obtain a white metal.

‡ A small fractional percentage of silicon in the welding rod helps to keep down the zinc vapor. Hence, the name "low-fuming" for such rods.

Braze-Welding Field

Though the temperature range, 1600 to 1750° F, noted in Table 1 and above, is rather narrow, the process itself is one of the most versatile of all of the joining processes. Applicable to all of the copper alloys of Table 3 with the exception of Groups 8 and 9, it is also applicable to nearly all nickel alloys and nearly all cast irons and steels. It is not employed on the aluminum, magnesium, titanium or the white metal die-casting alloys. It is an invaluable repair or maintenance tool. At the same time, it has many advantages as a production tool, particularly in industries based on sheet steel, as the metal furniture industry.

The reasons for this widespread use involve the properties of the bronze alloy itself as: (1) the ready surface-alloyability of the molten bronze with the hot base metal, (2) the low yield point and high ductility of the hot solidified bronze which enables it to absorb shrinkage stresses without harm to itself or to the base metal, (3) the high strength and good ductility of the bronze filler metal after it is cold and (4) its good corrosion resistance as well as its good wear resistance.

In addition, the moderate temperatures employed in braze welding are, in most cases, harmless to the base metals occasioning little distortion. Moreover, there are many connections in which the braze weld is the most economical method of joining. Figure 2 illustrates an application of braze welding in the restoration of a broken cast-iron drive sprocket. This repair, quickly made, developed the full strength of the part, and saved six weeks of idle time of the conveyor system had the user found it necessary to cast and machine a new sprocket.

Brazing as a Repair Tool

Numerous examples in the literature bring out these points. The *Welding Engineer*[55] reports a successful repair to a 15-ton cast-iron rolling-mill frame using braze welding. Four hundred pounds of bronze welding rod were melted by the oxy-acetylene torch to restore the mill to operation. The saving in time and cost of a new casting made the job worth while. A similar cast-iron base, weighing 3 tons and belonging to a cold heading machine, was broken by loads of 125 tons repeated 70 times per minute. A braze- welded repair in 8 hr at a cost of $60 saved the $1100 cost of a new casting.[57]

Walker[58] gives an exposition on the use of the oxy-acetylene torch and bronze welding rods for keeping his machinery in needed repairs. He comments on the economy in time, materials and over-all costs.

Keller[61] tells of the braze welding of a cast-iron column, 8 x 10 in. in section, belonging to a shear frame. An oxy-acetylene torch, burning 870 cu ft each

of oxygen and acetylene, heated the frame and melted 70 lb of manganese bronze filler rods in $7^3/_4$ hr to make the repair. Carter[62] reports the braze welding of an even heavier frame having $5^1/_2$- x $9^1/_2$-in. sections. Two welds were made in 20 hr, using 115 lb of high-strength bronze welding rods and the oxy-acetylene torch.

Yost[64] describes repairs to a heavy cast-iron crusher jaw which required 17 hr of welding time and 80 lb of $^1/_4$-in. bronze welding rod melted with the oxy-acetylene torch burning 920 cu ft each of oxygen and acetylene. He further describes the restoration of heavy bronze bushings by brazing.

Morton explains[58] how to determine the strength of a projected braze weld in cast iron by a very simple test. He uses the oxy-acetylene torch to heat the surface of the cast iron as in making a braze weld and builds up a pyramid of bronze thereon. He knocks off the pyramid with a sidewise blow from a heavy hammer. The bronze should pull out a deep piece of cast iron from the brazed area.

Wanamaker[60] writes of the procedure for the use of the oxy-acetylene torch and bronze welding rod (no composition) in repairing both light and heavy machinery. In all of these reports, the preparation of the surface for brazing is emphasized.

In railroad maintenance, Bennett[67] shows economies in resurfacing locomotive drive boxes with silicon copper rod used as a metal arc electrode. His article is complete with cost and wear records. Longo,[68] on the other hand, reports good success with phosphor bronze to build up worn locomotive surfaces. Another type of $^7/_{16}$-in. diam cast bronze filler rod, having 77% copper, 8% tin, 15% lead, 0.45% phosphorus, was deposited by Holwill[69] with 1-in. diam carbon arc electrode carrying 700 amp. Kenefic[72] gives a still more complete description of their method of building up new and worn surfaces on locomotives.

Brazing as a Production Tool

The braze weld is used in the manufacture of a wide variety of products joining steel sheet metal, copper alloys, dissimilar materials as steel and a copper alloy, cast iron and steel and other combinations.

In some cases a nonsparking copper alloy is joined to a steel shank by braze welding. Graham[64] tells of joining brass tools to steel rod shanks by this method. In another instance, he describes the lengthening of an electric motor shaft by braze welding. In still another case, he describes the manufacture of a bronze cylinder by joining the halves by a temporary braze for purposes of machining.

Steel anchor lugs were braze welded to cast-iron water pipe[65] to take longitudinal tension bolts across the leaded bell and spigot joints. The shearing strength in the throat of the bronze fillet welds was 46,000 psi or 20,000 psi shearing strength of the bonding plane, bronze to cast iron. The cost was $6.00 per anchor. The brazing heat damaged the cement pipe lining only slightly.

In the manufacture and maintenance of laundry machinery, braze welding, as described by Jones,[66] improved the life of the Monel metal launders and reduced wash-wear on clothes.

Ayers[70] gives an extended discussion of applications of brazing to the manufacture of products from light gage metals, while Hawley[71] discusses automatic applications of the oxy-acetylene torch in brazing.

Spraragen and Rosenthal[73] in a very complete review of the literature to January 1944 (foreign literature to January 1941) on the welding of dissimilar metals, present an illuminating discussion in Parts III and IV of brazing and welding of copper alloys, one to another, and to ferrous metals. Too long to be quoted in detail here, one is recommended to look up this reference when investigating the problem of a connection between dissimilar metals.

Perhaps the most important recent development in brazing has been the use of a volatile flux drawn in through the acetylene line. This has been especially valuable in the manufacture of metal furniture and other products made up of sheet metal, torch brazed. Its value lies in (1) the elimination of flux dipping of the rod and stopping to coat the base metal with flux, and in (2) the elimination of the troublesome flux

Table 7—Copper and Copper Alloy Welding Rods and Arc Welding Electrodes

Common name	*AWS-ASTM classification*	*Nominal (desired) composition, %*						
		Copper	*Zinc*	*Tin*	*Manganese*	*Silicon*	*Phosphorus*	*Nickel*
Copper	ERCu	98 min (includes silver)	...	1.0	0.5	0.5	0.15	...
							Iron	
Copper-silicon (silicon bronze)	ERCuSi-A, RCuSi-B	94 min	1.5	1.5	1.5	2.8–4.0	0.5	...
		97 min	1.5	1.5	1.5	1.0–2.0	0.5	...
							Phosphorus	
Copper-tin (phosphor bronze)	RCuSn	94 min	...	4.0–6.0	...	...	0.20–0.30	...
	ECuSn-A	Rem.	...	4.8–5.8	...	...	0.15–0.35	...
	ECuSn-C	Rem.	...	7.0–9.0	...	...	0.35	...
							Iron	
Copper-nickel	RCuNi	67 min	1.0	1.2	1.25	0.10–0.50	0.6	29–33
Copper-nickel	RCuNi	Rem.	...	...	1.0	0.50	0.4–0.7	29 min
Copper-zinc								
Naval brass	RCuZnA(BCuZn2)	57 min	Rem.	0.25–1.0	...	...	...	...
Manganese bronze	RuCuZnB	56 min	Rem.	0.5–1.0	0.01–0.50	...	0.25–1.0	0.5
Low-fuming bronze	RCuZnC	56 min	Rem.	0.75–1.10	0.01–0.50	0.04–0.25	0.25–1.25	1.0
							Phosphorus	
Nickel bronze	RCuZnD	45 min	Rem.	...	...	0.04–0.25	0.25	9–11
							Iron	*Aluminum*
Aluminum bronze	ERCuAl-A1	Rem.	0.02	...	...	0.1	...	6.–9.
	ERCuAl-A2	Rem.	0.02	...	...	0.1	1.5	9–11
	ERCuAl-B	Rem.	0.02	...	...	0.1	3.0–4.25	11–12

The "R" classification indicates copper and copper-alloy welding rods for use as filler metal with the oxy-acetylene, carbon-arc and inert-gas (nonconsumable electrode) welding processes. The "E" classification indicates covered and bare copper and copper alloy electrodes for use with the shielded metal-arc and inert-gas metal arc (consumable electrode) welding processes.

Single values in this table indicate maximum percentages, except where otherwise stated.

glass which clings to the finished braze, making an expensive cleaning operation before the work can be painted. The vapor flux is drawn into the gas line and blown through the flaming nozzle in sufficient quantity to flux the base metal and the bronze. However, the residue of flux on the finished braze is so thin that it is cleaned off readily and does not interfere with the painting of the base metal.

Swift[74] shows that, with oxy-acetylene torch and fluxing equipment costing only $250, metal furniture may be assembled and brazed in a production line. He calls attention to the fact that "there is no flash or weld spatter to worry about; the flame-fluxing leaves no heavy beads of borax glass to be removed; the low temperatures required for braze welding minimizes distortion; the low fuming bronze shows a weld strength on steel of 55,000 to 65,000 psi; exact fit-up is not required as the bronze will fill up gaps."

Swift and Brown[75] comment on production jobs of various sorts using braze welding to join sheet steel in the manufacture of furniture, lawn mowers and other equipment made of sheet steel and tubing. They illustrate one application in which two oxy-acetylene torches, flame fluxers, low fuming bronze welding wire feeder work together automatically to make 15 in. of fillet welds per minute. Another advantage cited is that the brazing may be done in any position.

Similarly, Raffone[55] discusses the joining of sheet steel and steel shapes to make a variety of beds, chairs, desks, etc., by spot welding, arc welding and gas welding with emphasis on the last named method, using flux in the acetylene line and a low-fuming bronze welding rod. He remarks that the use of the gas-fluxer eliminates an expensive cleaning operation as a preliminary to painting.

Maynard[96] reports a unique welding job he did on a 1400-lb bronze bell which had cracked in service. The bronze, 82% copper plus 18% tin, was preheated to 600° F, metal arc welded (probably with phosphor bronze electrode) at 275 amp and cooled slowly. Returned to the church tower, the tone of the bell was found to be restored, and it could be heard at a distance of three miles.

Brazing in the automobile industry is discussed by Jacobs[76] who finds that with the oxy-acetylene torch and gas fluxer such results are secured as: (1) fast operation, eliminating postbrazing cleaning, (2) a lower temperature than fusion welding in automobile repairs, (3) reduced distortion, (4) applicable to any position and (5) savings up to 40%.

Brazing of Pipe and Tubes

Brazing is applicable to both ferrous and nonferrous pipes and tubes. Kilburn[79] tells of numerous plumbing installations made in England by braze welding. Since the bronze has ample strength, better than 50,000 psi for the low-fuming bronze, to carry stress across a connection, recessed fittings are not absolutely necessary as in soft soldering or silver brazing. And poor fit-up can be bridged if need be.

The bronze can be applied to connections in copper tubing, red brass pipe, galvanized iron pipe and cast-iron pipe. The strength of the joint in cold drawn copper tubing will be that of light annealed copper adjacent to the joint, the bronze filler metal being much stronger. The corrosion resistance generally is good. In the case of bronze-welded, cast-iron pipe buried in the ground, the iron becomes anodic to the bronze but, owing to its large area compared to that of the bronze weld metal, the electrolytic wastage of the iron is very slight. Moreover, the cathodic bronze develops a film which further resists electrolytic currents. Sprargen and Chiswik[80] published in 1942 a searching review of the literature on the corrosion resistance of welded joints, with brief mention of welds in the copper alloys having generally satisfactory performance.

Brazing Galvanized Steel

In addition to the joining of plain sheet steel for a thousand and one objects which are to be protected by further operations, as phosphate dip, painting, plating, enameling, etc., a large tonnage of steel sheet and ferrous castings are protected by galvanizing in the steel mill, foundry or factory.

In making connections on such material by brazing methods, the low-fuming bronze and the oxy-acetylene torch with or without volatile flux through the gas line has been used. As explained by Galbraith,[98] when properly done with a narrow flame and rapid action, little, if any, of the zinc is evaporated along the joint.

However, the literature shows quite a few examples of the use of the carbon arc and a copper-silicon alloy as the added metal. Eckberg and Gaylord[99] take the further precaution of coating the silicon bronze with tin. By the carbon arc method, a sharply pointed carbon is used with the arc held strictly on the silicon bronze weld metal. The steel is not fused. The connection is, in effect, a braze. Tuft[101] used the carbon arc and Everdur silicon bronze to manufacture small ship models of steel in thicknesses from 0.066 to 0.105 in. for test in the Taylor Model Basin. He remarks that such "brazes" had satisfactory strength and ductility and were easier to make, though somewhat inferior in strength, to helium protected, metal-arc steel fusion welds.

Simkins[100] had a still different approach to the problem of connecting galvanized steel. In this case, the steel was No. 11 gage galvanized used to make a 36-in. diam foundry ventilator stack. He used shielded, aluminum bronze metal arc electrodes.

Brazing, Braze Welding, Conclusions

Judging from the numerous references in the literature, brazing, including braze welding, is a very versatile process adaptable to sheet metal and tubing as thin as 0.015 in. thick and to sections in cast iron or steel as large as 50 sq in. or more.

Surfaces to be brazed should be clean, free from graphite, grease and dirt. Borax base fluxes are commonly used. Vapor flux introduced through the acetylene or fuel line (never through the oxygen line) dissolved in water-free alcohol, or methyl borate, is used. Vapor flux is satisfactory for thin sheet steel, but for heavy sections additional flux will be needed.

Advantage should be taken of capillary attraction wherever possible to draw the molten bronze between overlapping surfaces. Maximum strength, with a minimum amount of bronze, is thereby obtained.

Bronze surfaces offer good corrosion resistance and good wear resistance and can be applied by the oxy-acetylene torch, the carbon arc, the metal arc and the inert gas arc.

Copper-Hydrogen Brazing

1094° C (2000° F) to 1261° C (2100° F).

There are in the literature numerous references to the furnace brazing of steel in an atmosphere containing a desired 40% or more of hydrogen. Oxygen or air is, of course, excluded from the furnace atmosphere, as they make explosive mixtures with hydrogen. This joining process is in a narrow temperature range well above the liquidus temperature of copper and most copper alloys, and well below the solidus temperature of cast iron and steel. It is given separate mention because of its unique position in the temperature scale and because of its important commercial applications.

Jevons[83] has an historical approach to copper-hydrogen brazing, citing the early British Patent 5232/1910 granted to A. C. Hyde of Wolverhampton in 1910. The process was slow in getting started, using a hydrogen atmosphere in a high-temperature, 2050° F, furnace partly because of the slowness in securing a satisfactory furnace and partly because of the explosion hazard of hydrogen and air (oxygen). The first industrial use of the process was in 1933.

Steel may be heat treated or vitreous enameled *after* being copper-hydrogen

brazed. This is not possible after silver brazing or after brazing with the yellow or white bronzes.

C. Rhyne, Jr.,[81] reports a very complete investigation into the strength of copper-hydrogen brazed joints in SAE 1010 and 4130 steels for aircraft applications. Effects of (1) area of bond; (2) finish of surfaces, (3) clearances between mating members; (4) protective (brazing) atmospheres; (5) time of brazing; (6) parent metal; (7) heat treatment after brazing; (8) contamination of brazing; (9) diameter and thickness of tubular members; (10) misalignment of members.

The joints were brazed with copper wire at 2050° F in a reducing, dry, gas atmosphere free of CO_2, heating-to-cooling below oxidizing temperature. The individual effect of the above variables is shown in 14 tables too long to be reproduced here. Excellent graphical representations and photomicrographs are given. An over-all summary indicates that (1) SAE steel tube joints, copper brazed, may be designed to fail at a stress above 30,000 psi for a wide range of finishes, clearances, fits, diameters and wall thicknesses; (2) that the yield strength of the parent metals have much influence on the strength of the joint. Thus, joints in 4130 steels can be designed for shear strengths of 25,000 psi minimum, whereas the softer (lower yield strength) of 1010 steels will develop joint strength of only 17,000 psi minimum unless the metal is made excessively thick.

Tylecote[82] made a somewhat similar investigation, finding a clearance of 0.002 in. for $^1/_2$-in. rod and 0.005 in. for $^1/_4$-in. rod to be optimum, with time of brazing not critical. He found no improvement as a result of a solution heat treatment and aging.

An excellent discussion of the process is given in the WELDING HANDBOOK,[2] p. 504, under "Furnace Brazing." Various types of atmospheres and methods of loading and unloading the furnace are described. Kelley[83] investigated copper-brazed joints in four steels having carbon 0.12 to 1.05% and found that the strength of the joint paralleled that of the parent metal as the latter property was varied by heat treatment. Kuhlmann[84] obtained generally good results in samples brazed in a continuous furnace using an atmosphere of dissociated city gas, different brazing times, fits, etc.

Peaslee and Boam[87] reported an unusually thorough investigation of brazed joints looking toward a braze that would withstand high service temperatures, in a turbine compressor, for example. Test specimens for testing in tension, shear, impact and penetration were brazed in an electric furnace usable up to 2300° F in an atmosphere of dry hydrogen gas having a dew point as low as −100° F. Used as brazing alloys were: (1) Oxygen-free copper, (2) 85% silver–15% manganese and (3) an alloy of composition 0.45 carbon, 4.50 silicon, 15% chromium, 4.00% iron, 3.75% boron, and 72.30 nickel. The base metal was AMS steel No. 5770 (0.45 C, 1.50 Mn, 0.65 Si, 20.0 Cr, 20.0 Co, 4.0 Mo, 4.0 W, 4.0 Cb, remainder Fe). They note difficulty in copper-brazing steels having more than 0.5% chromium or which are high in aluminum or titanium in a dry hydrogen atmosphere.

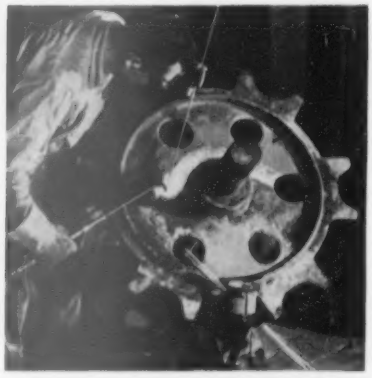
As a result of their searching tests, they reject the copper and the silver-manganese brazing alloys for service temperatures above 800° F, at which temperature butt tensile tests efficiencies are, respectively, 61 and 37%. The brazing alloy of (3) above, on the other hand, starts with an efficiency of 90% at room temperature and has 100% efficiency at all temperatures above 1500° F, being as satisfactory as the unbrazed base metal at 2000° F.

This last is surprising, as it has a solidus temperature of only 1850° F. The investigators explain this anomoly by saying that this brazing alloy and the No. 5770 are mutually soluble. Hence, the brazing alloy has diffused into the base metal at the brazing temperature of 2150° F. This fact inhibits penetration of the brazing alloy to the same extent that copper will penetrate. It also explains the high temperature head used for speedy brazing. Acrylic resin is a suitable binder for holding the powdered brazing alloy of (3) above in place with no interaction with the metals or the dry hydrogen.

Perhaps the near ultimate in copper-hydrogen brazing is detailed by Giroux[85] in which 120 different, variously shaped parts of steel weighing a total of $14^1/_2$ lb are assembled and copper-hydrogen brazed to make a four-cylinder engine block for a light automobile.

Fig. 1 Phosphorus deoxidized copper vessel, having $1^1/_8$-in. thick shell, being welded with the inert-gas, consumable-electrode method using copper-tin-silicon-manganese wire. (See references 102, 108 and 112)

Fig. 2 Braze weld on conveyor drive sprocket using oxy-acetylene method and low-fuming, high-strength bronze filler rod



Fusion Welding of Copper and Copper Alloys

General. Fusion welding of copper and copper-alloy base metals must, of course, be accomplished at temperatures above the liquidus or within the range 885° C (1625° F) to 1261° C (2300° F). These are all nonpressure welds with the exception of resistance butt, spot, seam and stud welding. The common nonpressure fusion welding methods are oxy-acetylene, bare metal arc, shielded metal arc, inert gas metal arc, carbon arc. The inert gas metal arc for the copper alloys employs helium gas, argon gas or mixtures of these two gases. The process is further divided into (1) inert gas tungsten (nonconsumable) electrode metal arc, or (2) inert gas, consumable copper alloy electrode metal arc. In designs where a connection is desired having the properties of the annealed base metal, a filler material is generally available.

Chapter 34 of the WELDING HANDBOOK[2] gives an excellent survey of welding methods for the copper alloys as they were available in 1949.

A. N. Kugler in Chapter 32 of the ACS Monograph "Copper"[90] brings us up to date, January 1954, with welding processes and applications summarized from 17 references.

The above two references are too long to review in detail here. The designer should, however, refer to them when in doubt as to a particular application. The various fusion welding processes will be discussed briefly below as they apply to each group from Table 3.

The *oxy-acetylene* is the oldest established method of fusion welding copper. The Review of 1936 cites the fusion welding of copper as early as 1912, 1915, 1917, 1927 and others. The oxy-acetylene process is still used and improvements have been made since 1936. The following citations will illustrate the fact.

Fig. 3 Chemical vessel of copper-silicon-manganese alloy welded with the inert-gas, tungsten-arc method and copper-silicon-manganese alloy filler rod

As will be noted from Table 3: (*a*) the oxygen-bearing tough pitch copper is in one class as regards fusion welding, while the (*b*) oxygen-free or deoxidized copper is in another class. This distinction is brought out repeatedly in the literature,[3, 11, 90] and in numerous other places. It is very important in oxy-acetylene fusion welding operations (though not at all important in soft soldering, silver soldering and not too important in brazing).

C. E. Swift and the writer[91] in an extended research on the welding of toug' pitch and deoxidized copper, found a decided preference for the latter, as did Vreeland.[92] Cook and Davis,[93] in a comprehensive investigation, were equally sure that phosphorus-deoxidized-copper base metal was more weldable than tough pitch copper in both the arsenical (0.40% arsenic in base metal only) and nonarsenical grades. They used the 1% silver-copper welding rod. Benefits from the substitution of phosphorus-deoxidized (phosphorus 0.05 to 0.10%) base metal for the oxygen-bearing base metal were improved weldability, strength and soundness in the welded seams of $^1/_8$- and $^9/_{16}$-in. thick copper plate. They noted also that either arsenic or phosphorus would raise the annealing temperature of copper.

Young[94] also concluded that the deoxidized copper was more weldable than oxygen-bearing copper, though, in his investigation, the carbon arc and phosphor bronze welding rod was used and not the acetylene torch, as was the case with the other researchers.

The objection to the use of oxygen-bearing tough pitch copper has been explained many times. The free hydrogen atoms in a gas flame will penetrate several thousandths of an inch below the surface of red hot copper to react with cuprous oxide present in the copper to form steam. This high pressure steam makes surface cracks in the heat-weakened copper. West[11] gives an excellent exposition of this reaction with photomicrographs of the damaged copper. The filler rod for deoxidized copper base metal should also be deoxidized to improve the soundness of the weld metal.

An extensive research in the laboratory of The American Brass Co. resulted in the development of a proprietary alloy containing tin, and deoxidized with silicon and manganese.[95] This filler rod developed originally for the oxy-acetylene and the carbon arc processes has also found widespread acceptance for use in inert-gas-shielded arc.

This (ERCu) and other filler rods are tabulated in Table 7, which is abstracted from the tentative specifications for copper and copper alloy filler rods and electrodes issued jointly by the American Society for Testing Materials and the American Welding Society.[42]

Important Similarity and Distinction

It may be observed that the "R" welding rods in the copper-zinc classification of Table 7 are identical with the last three alloys of Table 6. The reason for this is rather important: The rods of Table 6 and the "R Copper-Zinc" rods of Table 7 are *brazing* metals for all of the copper alloys in Table 3 including 85/15 red brass and other brasses having less than 15% zinc. But for brasses having 30 to 42% of zinc, they are *fusion* welding rods and are unsatisfactory as brazing rods. The high zinc brasses, naval brass, Muntz metal and manganese bronze used as base metals should be melted simultaneously with the addition of the filler metal.

In selecting an appropriate welding rod from Table 7 to use on a base metal of Table 3, the normal procedure would be to select a rod of the composition which is nearest to that of the base metal. However, this does not in all cases bar the use of a different rod, electrode or welding process.

While the oxy-acetylene torch is the oldest method of welding copper, it has been largely superseded by the inert-gas arc. These newer methods are less likely to have hydrogen in the flame, so that the tough pitch copper is not likely to be as severely embrittled as it would be in an oxy-acetylene or oxy-hydrogen flame. And the intense concentration of heat in the arc enables the operator to make a pass so quickly that there is a minimum opportunity for the cuprous

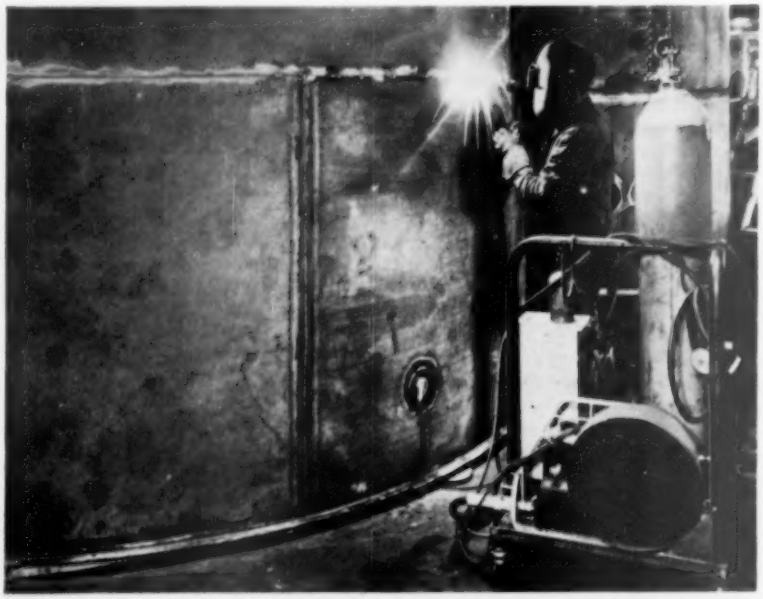


Fig. 4 Hot water storage tanks welded with inert-gas, consumable-electrode method

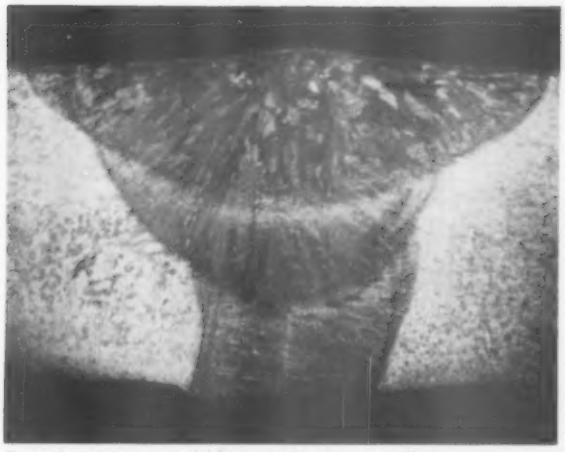


Fig. 5 Weld in $^1/_2$-in. thick copper-silicon-manganese alloy using the inert-gas, consumable-electrode method. Macro, X 4. Copper-silicon-manganese alloy wire. Full strength developed in the weld

Fig. 6 Micrograph (X 75) of the weld of Fig. 5 at junction of weld metal (*top*) and original base metal (*bottom*)

oxide-copper eutectic to collect at the grain boundaries.

This fact led Chyle[96] to suggest that electrolytic tough pitch (oxygen-bearing) copper may be used in copper weldments as an equivalent of deoxidized copper.

However, most authorities do not agree. They have found that the better weldability and greater reliability of the phosphorous deoxidized copper makes the latter preferable for such important copper weldments as pressure vessels, chemical equipment, etc.[92–94, 97, 7] Figure 1 is a vessel of this type. The $1^1/_8$ in. thick deoxidized copper shell is welded with the inert-gas consumable-electrode process. The electrode is of the ERCu type of Table 7.

Chyle[96] reported, in the 1951 Adams lecture, a very thorough investigation in the welding of copper as a preliminary to the manufacture of reactors which were lined with welded copper plate $^1/_8$ in. thick. Some of the more pointed conclusions reported in this lecture are:

1. The pure tungsten (nonconsumable) electrode is preferred to the thoriated-tungsten electrode for the inert-gas welding of copper. The latter results in deep undercutting of the parent metal.

2. Helium was preferred to argon as the shielding gas. The higher voltage required in the arc with helium and its higher specific heat as compared to argon are cited as advantages.

3. Direct current with tungsten electrode negative (straight polarity) is preferred to alternating current or direct current with reversed polarity.

4. Tough pitch copper, phosphorous deoxidized copper, and OFHC copper are ruled out as filler rods, while those having tin, silver and/or silicon are acceptable, having weld strengths and ductilities comparable to the tough pitch and deoxidized copper base metal. These rods would have compositions within the limits of ERCu of Table 7.

In the above method of arc welding, helium or argon gas-shielded, nonconsumable, tungsten electrode, the electrode must be an appropriate size for the thickness of the base metal and the size of the filler rod. The nozzle must be cooled, preferably by water, and a reasonable amount of skill exercised by the operator. Figure 3 illustrates the use of the inert-gas, tungsten arc, to make sound, high-strength welds in silicon copper alloy plate.

A still newer method of using inert-gas shielding is with a *consumable electrode* fed automatically into the arc as it is melted. Several different designs of the apparatus are described in the literature. Muller, Gibson and Roper[102] announced the use of an automatic travel head and an automatic hand nozzle for feeding a flexible wire electrode through the helium or argon protective gas into the arc which springs from the melting wire to the base metal, which is melted at the same time. In a series of 12 references, they trace the development of the process from the work of G. E. Doan[102] and others from 1936 on.

Muller and associates[102] remark that the process is basically sound as it is not complicated by fluxes, slags, chemical reactions or gas molecular changes, while the arc in reversed polarity effectively removes the surface oxide film from the crater. Moreover, the metal transfer is very efficient with the exception of brass wire which loses some zinc by evaporation in the arc.

One important point they bring out is that above a certain minimum current density, which varies with both size and material of the electrode, "the transfer through the arc changes from large globular drops with erratic action of the arc and considerable spatter to a spray of extremely fine droplets, which are projected from the end of the electrode in the direction in which it is pointed." This point was investigated further by Muller, Greene and Rothchild[108] who noted a "stiffness" in the metal spray at high current densities giving it excellent directional control and enabling the operator to weld in any position.

Robinson and Cook[109] report an important advance in the inert-gas consumable metal electrode process in the use of stranded electrodes where the strands are different metals. As is well known, it is commercially impracticable to make certain alloys into wire, e.g., it would be virtually impossible to draw 85 copper–15 tin into wire, while 85 copper–15 zinc draws readily into very fine wire. On the other hand, most elementary metals are ductile. Hence, any desired weld deposit may be made by stranding together wires of the elements or alloys having the needed areas to yield the desired proportions. As a practical result, the elements in the different wires in the high temperature of the arc and in the extremely small droplets attain a state of homogeneity in the weld metal better than that of a casting having the same composition.

Robinson and also Lewis and Stirn[110] patented composite stranded or wrapped electrodes which would give a deposit by the shielded metal arc method of a desired composition such as could not be obtained in a single commercial rod or wire.

For the copper alloys, the minimum current density for the fine spray is rather high, being of the order of 100,000 amp per square inch. Hence, small diameter electrodes around $^1/_{16}$ in. are used for the most part. In turn, this means a high burn-off rate of the order of 20 fpm. Hence, even though the arc voltage is held constant automatically, the ele-

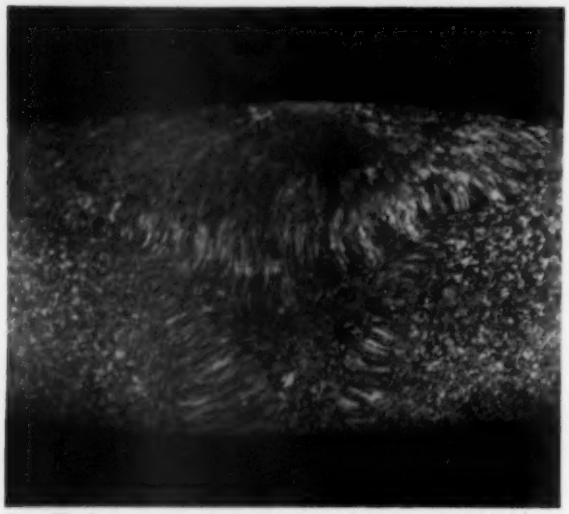
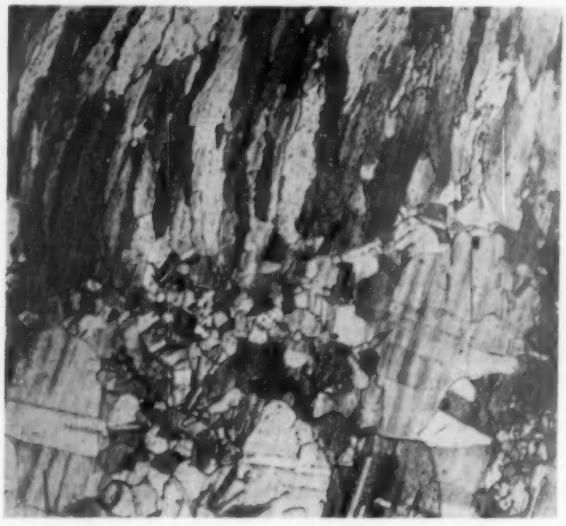


Fig. 7 Inert-gas, consumable-electrode weld in $^3/_8$-in. thick aluminum bronze (92 copper, 8 aluminum) plate using aluminum bronze wire. Note general soundness of the metal. Macro, X 5

Fig. 8 Micrograph (X 75) of junction of weld metal (top) and base metal (bottom) of Fig. 7. Note the columnar crystals of the weld metal and the equiaxed grains of the original base metal with a zone of fine-grained recrystallized metal between



ment of skill is involved—especially in a manually held nozzle. However, excellent results in terms of weld metal quality in the copper alloys is reported by the above and others.

Figure 4 shows the manufacture of hot water storage vessels made of $^3/_{16}$ in. thick copper-silicon-manganese alloy plate. Welded with the inert-gas, consumable-electrode arc, the welding wire, is the same composition as the base metal. It results in a high-efficiency weld. Note that the directional effect of the high-intensity arc enables the operator to make the weld in the difficult horizontal position on the vertical surfaces.

Figures 5 and 6 show welds in the copper-silicon-manganese alloy. Note the soundness of the metal and the perfect diffusion of weld metal to base metal.

Conway[104] calls attention to the patent of H. M. Hobart in the early 1930's on the use of helium for welding. The hotter arc of a given length in helium over that in argon is due to the fact that the voltage across the arc in the former is 40% higher than in the latter. The energy is proportional to the voltage for a given current.

Robinson and Berryman[105] give a further and more complete investigation of the use of the inert-gas, consumable-electrode metal-arc process in welding ten copper alloys in thicknesses from $^3/_8$ to $1^1/_2$ in. Electrode wires of aluminum bronze, silicon bronze, phosphor bronze and deoxidized copper yielded welds of good commercial strength, ductility and soundness without exceptional skill on the part of the operator.

Yaczko[106] explains commercial applications of the process calling attention to difficulties in joining Everdur to steel (cracking in the weld crater). Deposits made with aluminum bronze electrode wire were less likely to crack.

Rockefeller and Herbst[107] explain a welding process using the inert-gas arc and the consumable electrode automatically fed into the arc. Rockefeller calls attention to the fact that "The use of inert gas has become a major welding process in less than a decade, i.e., 1941 to 1951. And it has not only largely replaced other methods, but has permitted fabrications hitherto impracticable for welding."

Rockefeller[107] notes that alternating current is preferred for welding aluminum, magnesium and aluminum bronze with the tungsten electrode, and direct current for all other metals. He calls attention to several benefits from the use of the inert-gas consumable electrode process, thus:

1. Eliminates flux and resulting slag. Particularly important in welding aluminum and magnesium since most of the fluxes used therewith are corrosive.

2. Characteristically higher current densities—yielding deep penetration, narrow welds, smaller heat-affected zones and reduced distortion.

3. Rapid deposition results in reduced costs.

Wooding[111] gives an excellent survey of the inert-gas, metal-arc process with an historical approach, illustrated by a picture of a welding shop of 1887 in which the carbon arc and battery current was being used, DeBernardos having invented the carbon arc in the 1860's, while Slavianoff tried the metal arc shortly thereafter using a bare metal electrode with indifferent success. Kjellberg of Sweden coated the metal electrodes (time not stated).

Wooding[111] also reports L. J. Weber as having in 1926 tried welding in helium atmosphere reporting his work in *Trans. Am. Soc. for Steel Treating*, **XI** (1) 1927. He also notes that high current densities of 40,000 to 70,000 amp per square inch are needed for stable metal arc in inert-gas atmosphere with electrode positive. His work was done mostly on aluminum.

The Welding Journal[112] reports the welding of 1-in. thick copper at Ansonia Copper and Iron Works with deoxidized copper consumable electrodes $^1/_{16}$ in. diameter using 470 amperes, 157,000 amperes per square inch, reversed polarity, in helium-argon gas. The burn-off rate was 33 feet per minute with 5 passes needed, including the root pass, to weld the 1-in. thick metal.

The Welding Journal[113] reports another interesting job where a high-speed tubing machine built by the Yoder Co. for the Bridgeport Brass Co. heats the abutting edges by induction and proximity effect to make the longitudinal fusion weld in copper alloy skelp in thicknesses from 0.025 to 0.134 in.

Jewell[114] describes the first welding of large copper tanks by the use of the inert-gas, shielded, tungsten arc with straight polarity. He used $^1/_4$-in. diam copper-silicon-manganese filler rod. As a result of this work, he recommended: (1) That welding be done in cooler weather to reduce operator fatigue—welding in this case was done at 115° F temperature and 95% humidity; (2) and that there be cleanliness of metals and site.

The welding of rotor bars of copper alloy to copper end rings in the manufacture of alternating-current electric motors is described by Huff.[115] An automatic inert-arc process is used to

fuse the parts together making a strong and electrically efficient joint.

Another method of welding, in this case the carbon arc, is used to weld the armature wires to the copper commutator bars in the manufacture of 3- to 5-hp direct-current electric motors in which there are 65 connections.[116] A water spray protected the insulation from the welding heat. A copper tank, 8 ft in diameter by 18 ft long, made of $^3/_{16}$-in. copper sheet with $^1/_4$-in. thick copper heads was welded satisfactorily with the argon-shielded arc.[117]

All of the ten groups of copper alloys of Table 3 may be welded by one or the other of the inert-gas, arc-welding processes. However, the copper-zinc alloys —brasses and bronzes—of Groups 3 and 4 are prone to lose zinc by evaporation in the high temperature of the arc. Fuming of zinc is troublesome and must be kept to a minimum.

Cadmium of the Group 10 bronze is also prone to evaporate in the high temperature of the arc. Cadmium vapor is toxic and extra precautions must be taken to avoid this hazard when cadmium-copper alloys are welded.[118]

Little work has been done in fusion welding high zinc alloys (as those of Groups 3 and 4 of Table 3) by the inert-gas-shielded arc. However, silicon bronze and aluminum bronze work quite well as consumable electrodes in the inert-gas-shielded arc and are much used therewith.

Walker[123] reports the welding of $^1/_4$- x $^5/_{16}$-in. naval brass plate using the carbon arc and low-fuming bronze rod and silicon-copper rods.

Ronay[124] cautions against the locked up stress near the weld in naval evaporator shells 6 ft in diam by 6 ft long of $^5/_{16}$-in. naval brass plate. In some cases it was as high as 9000 psi. He recommends a stress relief anneal at 750° F held for $1^1/_2$ hr for each $^1/_2$-in. of thickness and cooled slowly to avoid stress-corrosion cracking in service.

Schlosser[121] reports the welding of a heavy hydrolyzer made of $^{13}/_{16}$-in. phosphor bronze, 96% copper–4% tin, using a bare phosphor bronze metal arc electrode. He had tried the carbon arc and the oxy-acetylene methods previously with poor success. With the metal arc, he obtained satisfactory welds having a strength of 39,000 psi. This was in 1941 before the inert-gas arc became well established. Sandberg[125] the next summer reported a similar welding job on a large, phosphor bronze pressure vessel attaining good results with a low-phosphorus bronze *covered* metal arc electrode.

Spencer[119] gives a rather comprehensive survey of various preferred methods of welding the copper alloys, citing 16 references. The articles are well worth consulting but are too long to be abstracted here.

Richards[20] gives a very complete dissertation on the joining of beryllium copper, Group 9. For fusion welds he suggests the carbon arc or the inert-gas arc using either beryllium copper, Everdur, or aluminum bronze rod for filler metal.

Hawthorne[120] obtained excellent results in welding the 90/10 cupro-nickel using the inert-gas-shielded processes and the 90/10 cupro-nickel welding rod or electrode. Tensile strengths up to 50,000 psi with excellent ductility were obtained.

Aluminum bronze covered electrodes are available and are found useful in metal arc welding of aluminum bronze and other alloys. Garriott[121] reports a very complete series of tests made to conform to ASME Boiler Code Special Case No. 1108 published in *Mechanical Engineering* February 1950. Carbon arc, inert-gas arc with both tungsten and consumable electrodes and submerged arc processes were tried. Good results were obtained and recommendations made. Earlier tests were reported by Swift[49] on the use of these coated aluminum bronze electrodes in making deposits requiring a strong, hard, wear-resisting surface on various base metals. On steel this would be an arc braze rather than a fusion weld, the arc being kept on the filler metal.

Sandberg[125] explains the use of the metal arc and phosphor bronze-covered electrodes in the welding of heavy phosphor bronze plate. This was in 1942 before the inert-gas arc had been perfected for the copper alloys.

Figures 7 and 8 are taken from welds made in $^3/_8$ in. thick aluminum bronze (92 copper, 8 aluminum) plate using wire of the same composition as an inert-gas, consumable, metal-arc electrode. In Fig. 8, the columnar crystals of the weld metal blend perfectly with the equiaxed grains of the base metal. A band of recrystallized fine-grained metal is noted in the interface.

Generally speaking, all of the copper alloys of Table 3 may be fusion welded. However, not all processes are equally well adapted to all alloys. The selection of welding process and filler metal must be determined after considering the application in which the weldment is to be used.

Resistance Flash, Spot, Seam and Stud Welding

This is the only welding process in which the high electrical conductivity of copper occasions difficulties. In the interval since 1936, noteworthy progress has been made in this field. Some valuable research on resistance welding was done at Rensselaer Polytechnic Institute[126] under the direction of the late Dr. W. F. Hess. He remarked that Dr. Hotchkiss, President of Rensselaer Polytechnic Institute, had said in October 1937 that "The joining of metals, including welding, was still more of an art than a science." However, much was done under his direction to change this situation.

Much was done also by the resistance spot and seam welding machine designers and the designers of resistance flash and butt welding equipment as well. In particular, the use of stored energy in a magnetic coil or condenser bank gave an impetus to resistance spot and seam welders making them applicable to aluminum with a minimum energy supply. Mikhalapov and Weygandt[127] in 1940 made a careful theoretical evaluation of the stored-energy spot welders of the electro-magnetic field type, while Hilbert[128] explained the practical application of the condenser discharge type in spot welding aluminum.

Dawson and Wise[129] give a still more searching report of the stored energy systems. They mention L. W. Chubb and his percussion welding which was developed in the 1910–20 decade to make connections in incandescent lamp manufacture. Also patents of J. A. Heany in 1913 on electro-magnetic storage which was popularized in France by Sciaky and by Languepin. The former introduced his machine into this country in 1938–39. Wood[130] a month earlier published an evaluation of the two types of stored-energy spot-welding machines.

While the primary objective of much of the spot welding equipment noted above was the spot welding of aluminum in the manufacture of aircraft, it did extend the use of such processes for the copper alloys as well. Wood, Babin, and Atkin[132] tested the efficiency of spot welds by the torsional shear method in the silicon red brass (77Cu–22Zn–1Si) which brass had been found useful in the manufacture of refrigerator evaporators by resistance spot and seam welding.

Both Taylor[124] and Gillett[133] emphasize the need for sensitivity in the pressure control of spot welds made at high speeds. They suggest the use of light weight in the moving spot welding electrode in order to reduce the inertia forces. Taylor reports the reduction of the moving electrode mass from 150 to 2 lb. He obtained copper-to-copper and copper-to-leaded-brass spot welds with the more sensitive welding head.

Brandt[122] discusses the machine variables and methods of control in flash welding needed to weld the nonferrous alloys. The controls of heating times, current values, voltage, holding pressure, push-up pressures and times are much more critical for the copper alloys than for steel.

"Poke" or Stud Welding

In making fastenings to a plate, in which it is expensive and undesirable

to drill the plate, the structural member, the tank or other stator, a new method known as the "poke" weld is employed to weld studs thereto.

Herbst[126] in an early description of the inert-gas arc explains the use of this simpler equipment to spot weld liners to steel tanks in 4 sec per spot. He details applications involving pure silver, Monel, Everdur and other copper and nickel alloys. Pilia[127] describes an improved inert-gas welding head weighing only 2 lb which spot welds one sheet to another underlying it as in automotive work, refrigerator manufacture, etc.

Herbst also describes the welding of an 8 ft diam by 18 ft long tank made of $^3/_{16}$-in. diam Everdur and $^1/_4$-in. thick heads. In this instance, alternating current was used. In later work the direct current was found preferable.

Brewster[128] cites the advantages of stud welding where studs $^1/_8$ to $^3/_4$ in. diam are welded to steel, aluminum studs to aluminum plate, brass and Monel studs welded to a stator by the controlled cycle process. High-frequency pilot arc guides power arc stud to plate, flash of heat and then pressure completes the job in an automatic cycle. Arc times 0.15 to 0.50 sec with arc currents 150 to 500 amp. A suggested stud design is up to 3 times plate thickness.

A later development[129] is in a capacitor-operated stud welder which uses only 2 kva. With it one operator can place 3000 studs per hour with the air-operated, portable gun. Studs from $^3/_{32}$ to $^1/_2$ in. diam can be welded to thin sheet or heavy plate with a strength comparable to that of the heavy metal. Most combinations of metals are possible as, for instance, brass to zinc die casting.

Welding Goes to College

The copper industry is indebted to the colleges and technical schools for many of the advances made in the art of welding copper. This is not surprising, as an industry having such wide ramifications as the welding industry must necessarily be given the attention of the educators. Such is indeed the case. A vocational or technical school in any industrial community will almost invariably have a welding instructional department.

Professor Doan[102] did most of his work on the inert-gas arc at Lehigh University, while Professor Henry[141] used the facilities of Brooklyn Polytechnic Institute on important metallurgical studies of welds. Professor Harrelson[142] outlines the courses at Georgia Institute of Technology which orient welding to engineering, while Professor Schultz[143] does the same for Oklahoma A. and M. College. Professor Young[94] takes up welding at Michigan College of Mines and Technology.

Turnquist[144] published an excellent outline for the layout and instructional equipment for school welding shops. The outline is well worth studying

Ohio State University is the first to confer the degree of Welding Engineer. Other schools are slow in following this lead, but none of them are slow in recognizing the importance of the welding industry. Usually some mention is made of welding metallurgy in one or more of half a dozen departments of instruction.

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RESEARCH NEWS

Front-End Camera and Binocular Attachment

A new front-end plate camera and a new binocular attachment, both adaptable to all existing Philips EM-100 electron microscopes, have been announced by the Research & Control Instruments Division, North American Philips Company, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

The new camera permits micrographs to be made at direct magnifications up to × 100,000 direct at the viewing screen. Cassette holds five 3¼ by 4-in. or six 4 by 5-in. cut films.

Rapid single lever action removes the cassette from the field and presents fresh film in the automatic cassette. This eliminates double exposures. Camera is equipped with a direct reading exposure counter.

The binocular attachment is available and fits over the flange ring of the Philips 100-kv electron microscope. Objective lenses provide × 3.5 and × 7 magnification and aid in determining accurate image focus.

I. I. W. REPORT:

COMPARISON OF SLOW NOTCH-BEND TEST AND V-NOTCH CHARPY IMPACT TEST

For the assessment of the notch ductility of C-Mn steel

Introduction

At the present time steelmakers are being asked to provide carbon-manganese steel plates with notch ductility specified to attain various arbitrary levels. To ensure that the notch ductility of each batch of steel is satisfactory, specifications call for some form of notch-bar acceptance test.

While in any one country the test used for determining the relative notch ductility of steel for acceptance purposes is reasonably standardized, there are very marked differences in the characteristics of the tests employed in different countries. Further, even when the same type of test is used, the relative notch ductility of the steel may be assessed on the basis of one of a number of different criteria. The object of the present investigation was to determine the extent to which the procedure adopted for acceptance testing in different countries gave equivalent rating to a number of 1-in. thick carbon-manganese steel plates.

For a preliminary investigation, it was decided to consider only two of the many tests and two of the possible criteria. The tests selected were the V-notch Charpy impact test and the slow notch-bend test as developed at the Royal Netherlands Blast Furnaces and Steelworks. These tests differ with respect to rate of loading, type of notch and size of specimen. From either test it is possible to determine either the tendency for a cleavage crack to initiate at the notch and propagate through the undeformed metal (the ductility, criterion), or alternatively, the tendency for a fibrous crack to change to a cleavage crack after some deformation has occurred (the "fracture appearance" criterion). For acceptance testing, the former criterion is normally employed in the V-notch Charpy test, and the latter with the slow-bend test.

In addition to determining whether the different test and criteria rated the steels in a comparable manner, the opportunity was taken to investigate the reproducibility of the two tests when carried out in different laboratories, and also to make an estimate of their relative discriminating power.

This preliminary investigation was carried out on carbon-manganese steels of the same general type and on samples of the same thickness. Since the slow-bend test is normally carried out on specimens comprising the full plate thickness, while the Charpy specimen has the same dimensions irrespective of the thickness of plate from which it is taken, this latter factor will probably influence the relationship between the results of the two tests when plates covering an appreciable thickness range are considered.

Procedure

The experimental work was shared by five laboratories. Eleven plates of C-Mn steel, all 1 in. thick, were selected to cover as wide a range of notch ductility as possible. These specimens were provided from four works, each of which carried out both the V-notch Charpy and slow-bend tests on their own plates. In addition, one laboratory carried out check slow-bend tests on eight samples, and two laboratories carried out check V-notch Charpy tests, one testing eleven plates whilst the other excluded the three sam-

A report of Commission 9, International Institute of Welding, Behavior of Metals Subjected to Welding.
Document XII-139-54. Released by the Bureau of the I.I.W. and recommended for publication.

This investigation was carried out under the auspices of the former Commission 12: Brittle Fracture (now incorporated in Commission 9: Behavior of Metals Subjected to Welding) of the International Institute of Welding. The members of the Subcommission that was entrusted with this work were: W. Barr, *Chairman* (Great Britain), J. H. Van der Veen (Holland), Per Matton-Sjoberg (Sweden), H. Herbiet (Belgium), H. Vinter (Denmark).

Table I—Data on Steels Investigated

Code Letter	Composition, %					Yield Point		U.T.S		Elongation, % on 8 in.
	C	Mn	Si	S	P	Tons/sq.in.	Kg./sq.mm.	Tons/sq.in.	Kg./sq.mm.	
A	0·185	0·58	0·030	0·049	0·020	15·5	24·0	27·0	42·5	34
B	0·165	0·58	0·030	0·044	0·017	17·5	27·5	27·0	42·5	32
C	0·120	0·43	0·040	0·029	0·011	17·0	27·0	25·0	39·5	33
D	0·150	0·70	0·050	0·048	0·022	19·0	30·0	26·5	41·5	28
E	0·180	0·68	0·200	0·040	0·019	21·0	34·0	29·5	46·5	25
F	0·120	1·36	0·280	0·025	0·015	21·0	32·5	31·5	50·0	22
G	0·190	0·64	0·050	0·034	0·013	15·5	24·0	28·0	43·0	27
J	0·200	0·82	0·200	0·024	0·010	22·5	35·5	30·0	47·5	26
K	0·215	0·70	0·060	0·045	0·038	18·0	28·5	31·5	49·5	26
L	0·125	1·18	0·040	0·046	0·020	17·0	27·0	28·5	45·0	34
M	0·125	0·95	0·130	0·030	0·020	20·0	31·0	29·5	46·5	32

ples from its own works. The compositions and tensile properties of the steels were determined.

Experimental Details

In order to avoid spurious relationships arising from heterogeneity of the samples, test specimens were taken according to a prearranged plan. Each collaborating laboratory followed the same procedure in selecting specimens for testing, and testing temperatures were

Table II—Works Tests on V-Notch Charpy Specimens

Testing Temp., °C.	Energy, ft.lb.	Percent Fibre
Steel A		
+60	72, 79	90, 90
+40	66, 59, 70	80, 50, 70
+20	35, 47, 44, 54	20, 30, 30, 30
0	10, 29, 55, 21, 34	5, 10, 95, 10, 10
−20	6, 6, 7, 9	5, 5, 5, 5
−40	4	5
Steel B		
+40	56, 62	100, 100
+20	57, 61, 54	100, 100, 100
0	43, 56, 50, 42	80, 100, 100, 80
−20	29, 45, 44, 38, 29	20, 100, 90, 80, 30
−40	7, 5, 9, 17	10, 5, 10, 10
−60	3	0
Steel C		
+20	107, 116	100, 100
0	82, 119, 95, 118	80, 100, 90, 100
−20	80, 48, 58, 69, 85	70, 20, 40, 50, 60
−40	26, 20, 20, 20	10, 10, 10, 10
−60	7, 5, 8	5, 5, 5
Steel D		
+60	65, 62	100, 100
+40	53, 51	65, 70
+20	23, 29	40, 35
0	12, 14	15, 20
−20	6, 5	0, 0
Steel E		
+40	51, 51	100, 100
+20	47, 48	90, 100
0	29, 44	55, 95
−20	9, 29	10, 65
−40	5, 7	0, 5
Steel F		
+20	97, 102	100, 100
0	91, 99	95, 100
−20	44, 63	15, 15
−40	22, 42	5, 10
−60	14, 14	0, 0
Steel G		
+60	55, 50	75, 85
+40	38, 50	40, 90
+30	36, 35	35, 35
+20	30, 33, 29	20, 25, 20
+10	18, 33, 23, 16, 20	20, 25, 20, 20, 20
0	13, 12, 16, 12, 8	5, 5, 5, 5, 5
−10	11, 7, 11, 26, 12	0, 0, 0, 0, 0
−20	6, 6	0, 0
Steel J		
+20	76, 67	100, 100
0	76, 72	100, 100
−20	40, 69, 61	30, 40, 35
−30	42, 27, 36, 35, 30, 35	25, 10, 25, 10, 15, 20
−40	45, 35, 20, 42	15, 10, 10, 15
−50	20, 20, 24, 26, 27, 20	5, 5, 5, 5, 5, 5
−60	12, 17, 32	5, 5, 5
Steel K		
+80	68	100
+60	55, 69, 53, 59	90, 80, 80, 90
+40	41, 44, 43, 43, 55	50, 50, 60, 50, 60
+30	40, 35	40, 40
+20	29, 40, 27, 37, 37	30, 40, 30, 40, 30
+10	23, 17, 13, 27, 22	20, 10, 10, 20, 20
0	20, 13, 14, 10, 19, 18, 11	10, 10, 10, 10, 10, 10, 5
−10	5, 5, 8	0, 0, 0
−20	5, 5, 6	0, 0, 0
Steel L		
+60	108	100
+40	108, 86, 111	100, 100, 100
+20	107, 103, 98, 103	90, 90, 70, 90
+10	77	50
0	60, 56, 50, 81	50, 40, 30, 50
−10	82, 39, 35, 44	50, 20, 20, 10
−20	42, 28, 43, 45, 15, 31	10, 5, 20, 20, 10, 0
−30	38, 37, 22, 26, 25	5, 5, 5, 0, 0
−40	21, 31, 8, 11, 6, 27	0, 0, 0, 0, 0, 0
−60	5	0
Steel M		
+60	90	100
+40	93, 93	100, 100
+20	107, 122, 95, 114	100, 100, 100, 100
0	93, 104, 95, 93	70, 90, 100, 100
−20	77, 86, 50, 58, 57	60, 80, 40, 40, 60
−30	51, 58, 73, 39	15, 50, 50, 20
−40	28, 25, 17, 42	10, 10, 0, 20
−50	18, 29, 18, 43	0, 5, 0, 0
−60	7, 11, 9, 6, 12	0, 0, 0, 0, 0
Steel J (repeat)		
+20	79	100
0	75	100
−20	65, 39	60, 30
−30	40	25
−40	30	10
−50	21	0
−60	17	0
−70	8	0
−80	7	0
Steel L (repeat)		
+40	110	100
+20	110	100
0	74	40
−20	21, 31, 51	10, 5, 10
−30	15, 18, 28	0, 0, 0
−40	5, 8, 14, 8	0, 0, 0, 0
−60	2	0

Table III—Results of V-Notch Charpy Check Tests

Testing Temp., °C.	Check Test I		Check Test II	
	Energy, ft.lb.	Percent. Fibre	Energy, ft.lb.	Percent. Fibre
Steel A				
+80	82	100		
+60	77	95	86, 90	100, 100
+40	71	60	91, 64, 54, 56	100, 70, 80, 80
+30			69, 51, 38, 62	50, 50, 50, 60
+20	33	10	31, 42, 39, 41	30, 40, 40, 40
+10	20	10	28, 15, 21, 25	10, 10, 10, 10
0	26, 26	0, 0	12, 12	0, 0
−10	10	0	8, 9	0, 0
−20	6	0	7, 6	0, 0
−40	5	0		
Steel B				
+60	55	100		
+40	58	95		
+20	60	95	56, 52, 53	100, 100, 100
+10			54, 52	100, 100
0	55	80	52, 52	100, 100
−10	26, 30	50, 40	38, 42, 34, 38	60, 80, 70, 50
−20	22	40	28, 20, 20	50, 40, 40
−30	14	20	13, 12, 14, 16	10, 10, 30, 30
−40	9	10	7, 6	0, 0
−60	3	0	4, 4	0, 0
Steel C				
+20	120, 120	100, 100		
+10	100+	100	102, 91	100, 100
0	95	60	86, 72, 89, 95	80, 70, 90, 90
−10	75	50	62, 49, 40, 61	20, 20, 20, 20
−20	40	30	28, 29, 41, 33	10, 10, 40, 10
−30	25	20	16, 21, 19, 16	10, 10, 10, 10
−40	17	10	10, 10	10, 10
−50	10	0	8, 8	0, 0
−60	5	0	5, 6	0, 0
Steel D				
+80	53	100		
+60	54	100	49, 51	100, 100
+50			41, 46	90, 100
+40	55	95	41, 44	90, 90
+30			33, 33, 31, 31	50, 50, 70, 70
+20	28, 28	40, 40	28, 27, 23, 25	50, 50, 50, 50
+10	19	30	17, 17, 14, 15	20, 20, 10, 10
0	13, 14	20, 20	12, 12, 12, 11	10, 10, 10, 10
−10	8	10	9, 10	0, 0
−20	4	0		
Steel E				
+60	45	100		
+40	54	100		
+20	47	95	36, 32	100, 100
+10			36, 35, 33, 35	100, 100, 100, 100
0	37, 33	80, 80	31, 28, 33, 30	80, 80, 90, 90
−10	26	60	17, 23, 17, 25	50, 60, 50, 60
−20	11, 17	30, 30	9, 15, 9, 12	20, 40, 20, 20
−30			6, 12, 8, 7	0, 20, 10, 10
−40	3	5	4, 4	0, 0
−60	2	0		
Steel F				
+40	83	100		
+20	85	100		
+10			75, 84	100, 100
0	84	100	78, 73	100, 100
−10			50, 57	60, 70
−20	53	40	41, 44, 50, 51	50, 50, 30, 30
−30			28, 32, 29, 22	20, 20, 30, 30
−40	31, 32	10, 10	18, 24, 25, 24	10, 10, 10, 10
−50	15	0	12, 21, 17, 12	0, 10, 10, 0
−60	11, 13	0, 0	7, 7	0, 0
−70	10	0		
Steel G				
+80	73	100		
+60	69	100		
+50			53, 51	90, 90
+40	52	80	43, 56, 50, 46	50, 50, 60, 40
+30	51	60	41, 41, 38, 41	50, 50, 40, 40
+20	33	20	21, 23, 34, 32	30, 40, 50, 50
+10			17, 21, 29, 12	20, 20, 10, 10
0	24	10	17, 14	10, 10
−10	8, 6	0, 5	7, 10	0, 0
−20	9	0	7, 7	0, 0
−40	5	0		
Steel J				
+60	90	100		
+40	89	100		
+20	68	70		
0	40	15	62, 73	90, 100
−10	40	20	72, 55	100, 50
−20	29	5	57, 60	50, 50
−30	21	0	44, 47, 42, 35	20, 20, 30, 30
−40	14	0	22, 24, 27, 33	10, 10, 10, 10
−50	6	0	19, 17, 17, 19	10, 10, 10, 10
−60	5	0	20, 19, 18, 22	10, 10, 10, 10
−67			10, 12	0, 0
Steel K				
+70			63, 67	100, 100
+60			45, 51	70, 80
+50			38, 44	50, 50
+40			36, 36	50, 30
+30			32, 30	50, 40
+20			26, 27, 34, 22	30, 30, 20, 10
+10			20, 21, 11, 24	10, 10, 10, 20
0			12, 9, 14, 10	10, 0, 10, 0
−10			7, 8	0, 0

Table III (cont'd)

Testing Temp., °C.	Check Test I		Check Test II	
	Energy, ft.lb.	Percent. Fibre	Energy, ft.lb.	Percent. Fibre
Steel L				
+20			88	70
+10			81, 90, 69, 76	70, 70, 60, 60
0			44, 68, 76, 62	20, 30, 70, 50
−10			17, 21, 41, 47	10, 10, 30, 30
−20			39, 15, 20, 24	10, 0, 0, 0
−30			12, 10, 9, 19	0, 0, 0, 0
−40			6, 6	0, 0
Steel M				
+10			94, 89	100, 100
0			90, 93	80, 100
−10			95, 65	100, 60
−20			65, 74, 70, 64	50, 50, 60, 60
−30			43, 57, 46, 42	40, 40, 20, 20
−40			34, 20, 35, 17	10, 10, 10, 10
−50			10, 13, 11, 10	0, 0, 0, 0
−60			8, 8	0, 0

specified. The procedures for carrying out both the slow-bend test and Charpy tests are fully described in the literature, but the standard procedures laid down for the investigation are described below.

V-Notch Charpy Test

The test was carried out on specimens having their longitudinal axis parallel to the direction of rolling of the plate; the specimens were taken from a position 3 mm below the surface. Specimens were 10 mm square and not less than 55 mm or more than 60 mm long. Notches were cut with a milling cutter with an angle of 45°, the tooth radius being 0.25 mm. The notches were 2 mm deep. The longitudinal axis of the notch was perpendicular to the plate surface.

The testing temperature of the specimens was controlled by immersing them in a liquid bath. For temperatures below the atmospheric, a cooling mixture of methylated ether and solid carbon dioxide was employed. The temperature of the bath was measured by means of a thermometer or thermocouple. Specimens were held at temperature for at least 5 min, and then transferred to the machine as rapidly as possible and broken immediately.

Slow Notch-Bend Test

The test was carried out on specimens having their longitudinal axis parallel to the direction of rolling of the plate. The specimens were not less than 225 mm long with a cross section of 70 mm x 25 mm. A 3 mm deep notch was pressed perpendicular to the plate surface by means of a sharply ground knife edge of 45° angle. Testing was always completed within 2 hr of notching, to minimize the aging effects.

The vertical speed of loading was 20 mm/min. The testing temperature of the specimens was controlled by immersing them in a liquid bath consisting of methylated ether and solid carbon dioxide for temperatures below atmospheric. The temperature of the bath was measured by means of a thermometer or thermocouple.

Test Criteria

The criteria considered were as follows:

Slow Bend Test

Fracture Appearance Criterion—The temperature at which it was estimated that there would be a zone of shear fracture extending 32 mm from the root of the notch.

Ductility Criterion—The temperature at which it was estimated that the specimen 200 mm between supports would have deflected 6 mm at its central point when the load reached a maximum value.

V-Notch Charpy

Fracture Appearance Criterion—The temperature at which it was estimated that the areas of shear and cleavage in the fracture would be equal.

Ductility Criterion—The temperature at which it was estimated that the mean energy absorption to fracture the specimen would be 15 ft-lb.

Results

The compositions and tensile properties of the eleven steels are given in Table 1. Complete records of the results of V-notch Charpy and slow-bend tests are given in Tables 2–3 and 4–5, respectively. The transition temperatures obtained are shown in Table 6

Analysis of Results

The first object in analyzing the result was to determine whether the results obtained in different laboratories were sufficiently comparable to justify further consideration of the data. Owing to lack of specimens it was not possible to obtain a reliable estimate of the ductility criterion for the check slow-bend tests. However, the reproducibility of the fracture appearance criterion from the slow-bend, and the ductility and fracture appearance criteria from the V-notch Charpy test, were examined by plotting the results in the diagrammatic form shown in Fig. 1. From this diagram the following conclusions were drawn:

1. There is no evidence of any major systematic error in the values of any of the criteria. The temperatures obtained for the V-notch Charpy ductility criterion in the check tests seem to be somewhat higher than the results reported by the individual firms. This may be due to systematic errors in measuring temperatures in the lower range.

2. There are minor random differences in the results obtained in different laboratories for all criteria. However, in no case are these differences of sufficient magnitude to prevent a general classification of the steels.

3. The random error in the value of a criterion will depend on the number of specimens broken to determine it. For the particular number of specimens used in this investigation the slow-bend test has a significant

Table IV—Results of Slow Notch Bend Tests

Testing Temp., °C.	Works Tests			Check Tests		
	Max. Load, metric tons	Deflection at Max. Load, mm.	Depth of Fibre, mm.	Max. Load, metric tons	Deflection at Max. Load, mm.	Depth of Fibre, mm.
Steel A						
+40	29·8, 30·8, 30·1, 30·3	13·2, 13·8, 13·6, 12·2	52, 46, 46, 48			
+30	30·7, 32·1, 30·8, 31·1, 31·3, 31·8, 35·0, 32·9, 33·2, 32·9	12·2, 14·0, 13·3, 14·2, 14·4, 14·3, 17·0, 15·2, 14·9, 14·4	5, 37, 43, 42, 36, 38, 45, 46, 8, 41			
+20	30·6, 25·4, 31·4, 31·2, 33·3, 32·6, 32·1, 32·8, 32·8, 33·0	13·3, 6·7, 12·8, 13·8, 12·4, 14·0, 14·0, 14·4, 13·8, 14·0	11, 1, 5, 11, 3, 7, 34, 44, 8, 36			
+10	19·9, 32·4, 34·3, 29·1	3·2, 12·6, 13·0, 8·5	0, 6, 3, 2			
0	22·2, 21·9	4·0, 3·2	0, 0			
Steel B						
+20	27·6, 26·9	9·2, 9·9	67, 67			
+10	28·4, 28·8	9·5, 10·0	67, 67			
0	29·2, 28·6	9·5, 10·2	67, 67			
−10	29·7, 29·7, 30·2	9·7, 9·8, 9·4	67, 67, 67			
−20	30·2, 29·4, 30·6	10·0, 10·0, 9·2	67, 67, 67			
−30	30·0, 30·0, 32·0	9·4, 9·8, 10·0	67, 67, 67			
−40	30·6, 29·3, 29·8, 31·4, 30·7, 31·1, 29·1	9·7, 10·2, 9·6, 9·4, 10·0, 10·8, 10·9	60, 57, 58, 67, 60, 67, 55			
−50	23·0, 23·4, 24·4, 31·7, 23·4, 24·5, 24·3, 23·0	2·2, 2·4, 3·5, 9·5, 2·3, 3·0, 3·4, 2·0	0, 0, 0, 59, 0, 0, 0, 0			
Steel C						
−10	35·4, 37·1	19·0, 22·5	53, 60			
−20	36·3, 35·0, 34·8, 37·8, 36·2, 36·6, 36·2, 37·4	20·2, 18·2, 17·6, 21·8, 20·6, 19·6, 19·7, 20·7	59, 59, 57, 60, 39, 40, 15, 48			
−30	38·9, 37·4, 35·9, 33·6, 36·7, 38·9, 36·5, 37·9, 35·7, 37·5	22·6, 20·2, 18·6, 16·0, 17·9, 22·8, 17·5, 20·7, 17·5, 18·8	14, 13, 12, 32, 8, 50, 13, 26, 29, 41			
−40	29·7, 35·4, 29·5, 34·5, 36·5, 35·3	7·7, 15·6, 8·2, 14·4, 17·9, 15·9	1, 7, 2, 6, 14, 14			
−50	30·5, 27·1, 28·1, 29·1	9·0, 6·4, 6·0, 7·2	2, 1, 1, 1			
Steel D						
+50	28·5, 26·9	11·1, 11·1	64, 66			
+40	27·3, 26·5	8·6, 10·4	60, 67			
+30	27·2, 25·9	9·9, 8·6	58, 67			
+20	27·2, 27·9	9·2, 9·5	55, 58	29·0, 29·0	10·2, 10·3	52, 59
+10	29·7, 28·7	20·7, 11·2	36, 49	29·7, 30·6, 28·9	10·0, 10·0, 9·9	53, 45, 56
0	28·7, 29·5	9·8, 10·6	31, 20	30·8, 32·1, 29·7, 29·8, 30·5	10·1, 10·7, 9·9, 10·4, 11·3	9, 6, 34, 34, 12
−10	21·4, 22·6, 19·2, 29·1	4·2, 4·4, 2·6, 13·3	0, 0, 0, 21	21·6, 22·8	3·3, 4·0	0, 1
−20	19·5, 22·2	2·5, 3·2	0, 0			
−70	22·3, 20·4, 21·3, 23·0	1·8, 1·7, 2·9, 2·9	0, 0, 0, 0			
Steel E						
+20	26·7, 28·0	7·5, 5·8	67, 67			
+10	28·9, 28·3	9·0, 8·1	67, 67	29·3, 29·1	8·1, 8·1	67, 67
0	29·5, 28·8	7·5, 8·3	67, 67	26·9, 29·3	6·9, 7·9	67, 67
−10	—, 28·9	4·5, 9·3	2, 67	28·6, 29·6, 30·4, 29·8	6·0, 7·7, 8·0, 8·4	3, 67, 62, 67
−20	—, 29·2	2·9, 9·4	0, 63	27·3, 29·1, 24·8, 27·4	7·6, 6·2, 3·3, 6·9	15, 4, 1, 61
−30	29·4, 29·4, 23·1, 24·0	9·5, 8·1, 3·6, 4·2	6, 4, 0, 0			
−40	24·0, 23·4, 22·8, 23·2	3·1, 2·4, 3·3, 3·5	0, 0, 0, 0			
−70	23·7, 23·7, 23·4, 23·1	1·2, 0·7, 2·5, 2·6	0, 0, 0, 0			

Table IV (cont'd)

Testing Temp., °C.	Works Tests			Check Tests		
	Max. Load, metric tons	Deflection at Max. Load, mm.	Depth of Fibre, mm.	Max. Load, metric tons	Deflection at Max. Load, mm.	Depth of Fibre, mm.
Steel F						
0	36·8, 38·4	13·2, 12·8	57, 65			
−10	36·8, 35·2	11·8, 13·9	67, 67			
−20	36·5, 38·0	11·3, 12·4	56, 61			
−30	38·6, 37·1	11·6, 11·9	15, 56	37·4, 38·2, 37·0, 37·2, 38·2	10·3, 11·4, 10·8, 10·0, 12·1	57, 57, 59, 16, 16
−40	36·7, 37·4	13·2, 13·1	15, 24	37·8, 38·2, 38·5, 37·6	10·1, 10·8, 11·1, 11·0	27, 11, 9, 11
−50	—, 39·3	6·3, 11·3	0, 14	38·3, 37·3, 28·9	11·0, 10·1, 3·2	9, 17, 0
−60	38·8, 35·4, 40·9	15·5, 7·4, 12·1	20, 1, 8			
−70	28·9, 31·0, 28·0, 29·8, 31·2	2·8, 2·9, 3·6, 4·6, 5·7	0, 0, 0, 0, 0			
Steel G						
+40	29·8, 29·0	12·0, 10·0	67, 67	27·1, 27·0	9·3, 10·3	67, 67
+30	26·5, 29·8, 30·0, 27·5	10·0, 10·0, 12·0, 11·5	54, 19, 2 67	27·5, 27·3, 27·0, 28·3, 28·4	10·2, 10·0, 10·2, 10·8, 11·2	67, 19, 42, 48, 49
+20	30·0, 26·7, 27·6, 26·9, 29·9	11·3, 11·0, 8·0, 10·0, 10·0	11, 8, 33, 35, 5	27·7, 25·4, 28·6	10·8, 8·5, 10·8	16, 15, 8
+10	29·9, 20·8, 23·9, 21·9, 23·0	10·0, 4·0, 5·0, 5·0, 4·0	25, 0, 1, 0, 0	19·6, 28·1	3·0, 9·5	0, 7
0	29·6, 20·8, 28·5, 29·1, 21·8	11·0, 4·0, 11·0, 11·0, 4·8	11, 6, 9, 9, 0			
−10	20·7, 20·9, 18·3	4·5, 4·0, 4·0	0, 0, 0			
Steel J						
−10	35·7, 33·7	13·5, 12·0	67, 67			
−20	36·3, 34·1, 38·1	10·5, 12·0, 11·5	67, 67, 67	35·0	11·3	0
−30	38·1, 35·2, 36·7, 36·4, 36·5	11·5, 11·5, 13·0, 13·0, 12·5	50, 67, 67 57, 22			
−40	35·9, 35·1, 35·4, 36·5, 38·8, 35·6	12·0, 11·5, 8·0, 11·0, —, 12·0	67, 67, 18, 56, 51, 14	34·9	10·4	67
−50	37·0, 36·5, 36·0, 36·1, 34·1	12·0, 10·0, 13·0, 9·5, 10·5	6, 10, 7, 4, 5	35·4, 37·4, 35·4	10·8, 12·0, 10·2	67, 32, 9
−60	32·1, 32·5, 32·3	6·0, 6·0, 7·0	0, 0, 0	34·9, 35·6, 37·4, 36·6	8·4, 10·5, 11·9, 10·0	5, 9, 8, 5
−70				29·5, 37·0	4·3, 10·0	0, 6
Steel K						
+60	30·4, 29·8	10·7, 10·4	65, 55	32·8, 33·6, 31·9	11·1, 11·1, 10·8	67, 51, 54
+50	31·1, 31·4, 30·8	10·2, 9·6, 10·4	42, 48, 49	33·0, 33·9, 33·4, 32·8, 34·1	11·2, 11·4, 10·8, 11·4, 11·2	50, 19, 47, 9, 48
+45	30·8, 32·5, 30·6	—, 10·2, 10·2	39, 52, 64			
+40	31·5, 31·5, 32·1, 31·9, 30·9, 31·9	—, 11·8, 10·9, 10·0, 10·4, 10·2	29, 35, 12, 40, 25, 20	32·7, 33·5, 33·2	10·4, 10·8, 10·0	13, 25, 3
+30	31·7, 32·1, 30·8, 33·3	10·0, 9·6, 8·0, 11·1	11, 27, 2, 14			
+20	32·6, 30·0	9·1, 6·5	6, 2	28·4	6·7	3
+10	28·0, 28·0	4·6, 5·1	0, 1			
0	21·0, 26·1	1·8, 3·5	0, 0			
Steel L						
+20	33·3, 32·6, 34·9, 32·4	12·7, 10·7, 12·5, 11·9	58, 64, 37, 67	39·7, 38·2	16·5, 16·4	67, 67
+10	34·7, 35·2, 33·4	14·2, 12·7, 10·9	45, 21, 67	43·4, 40·7, 41·1, 36·5, 40·4	20·3, 16·8, 17·1, 14·8, 18·4	16, 25, 24, 40, 59
0	31·4, 34·3, 36·3, 34·2	10·9, 12·2, 13·0, 11·9	54, 48, 8, 46	40·0, 43·4, 44·4	16·9, 18·9, 20·7	31, 43, 14
− 5	30·8, 31·9, 33·0	10·4, 11·1, 11·8	40, 55, 60			
−10	35·8, 35·2, 35·7, 33·6	12·0, 12·2, 9·8, 12·2	13, 7, 14, 20	40·5, 42·9	15·7, 17·7	7, 6
−20	33·2, 20·3	12·2, 0·7	9, 0			
−30	22·0, 33·0	2·0, 10·9	0, 4			
−40	23·4	2·0	0			
Steel M						
−10	34·3, 34·3	12·9, 12·0	67, 67			
−20	33·8, 32·9	13·1, 13·1	67, 13			
−30	35·6, 35·8, 36·6	12·5, 12·0, 14·5	67, 67, 56	40·6, 39·9, 41·7, 38·1	17·2, 15·6, 16·8, 14·2	67, 55, 53, 59
−40	35·8, 35·5, 35·2, 35·8, 37·4, 38·1	12·9, 12·4, 10·9, 11·7, 14·0, 15·1	67, 7, 10 55, 36, 45	39·3, 41·3, 37·8, 40·4, 39·8	14·1, 14·7, 12·0, 16·0, 14·8	60, 15, 4, 19, 57
−45	37·8, 37·6	13·8, 14·7	17, 14			
−50	37·0, 36·2, 37·4, 37·1, 37·6, 40·3	15·8, 12·4, 9·7, 12·7, 13·8, 12·2	67, 24, 11, 25, 15, 17	43·0, 41·3	15·6, 15·3	8, 15
−60	37·1, 31·7	11·7, 5·6	43, 0	28·2	3·1	0
−70	37·1	11·3	6			

Table V—Supplementary Slow Notch Bend Tests

Testing Temp., °C.	Max. Load, metric tons	Deflection at Max. Load, mm.	Depth of Fibre mm.
Steel A			
+10		7·1, 3·1, 3·8	2, 0, 0
0		2·2, 2·8	0, 0
Steel B			
−60		2·5, 1·7, 2·3, 2·3	0, 0, 0, 0
Steel C			
−70		2·3, 2·3, 1·8, 2·6	0, 0, 0, 0
Steel L			
−20	25·1, 36·3	5·8, 15·6	0, 0
−40	28·9, 23·7	8·6, 5·1	0, 0
−50	22·3, 26·8	2·5, 3·9	0, 0
−60	22·4, 23·2	2·2, 2·8	0, 0
Steel M			
−60	45·4, 33·7, 26·9	17·7, 8·6, 7·5	5, 0, 0
−70	43·5, 28·2, 35·2, 30·0, 37·2	16·5, 2·8, 7·8, 4·3, 9·3	2, 0, 0, 0, 0
−75	33·8	8·0	0
−80	29·7, 27·8	2·4, 2·6	0, 0
−90	29·7	2·3	0

advantage over the Charpy test in that it spreads the results over the widest range of temperature and shows the best reproducibility between different works. On the other hand the Charpy fracture appearance criterion does not seem to discriminate between steels which have good notch ductility.

The main objective in analyzing the results was to determine whether the different tests and criteria gave a comparable, order of merit, rating to the steels. If the tests and criteria measure the same property of the steel, then the results should show a high degree of correlation. Since the number of results was too small to justify determining the correlation coefficients by arithmetical computation, particularly since there was no reason to believe that the relationships would be linear, values for the different criteria were plotted against one another and the degree of correlation was estimated from the scatter of the values from a smooth curve drawn through the points. These curves are shown in Figs. 2–6 and are discussed in the following paragraphs.

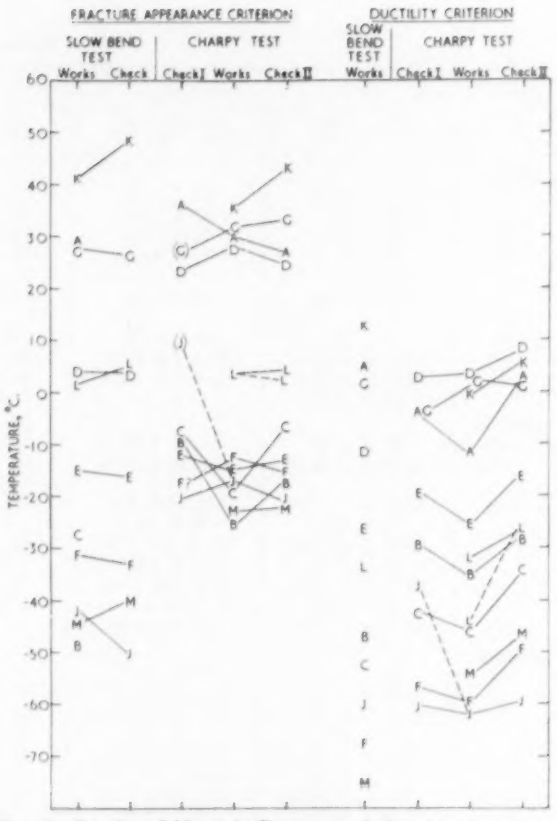

Fig. 1 Results of V-notch Charpy and slow-bend tests on eleven steels

Table VI—Transition Temperatures

Test	Criterion	Transition Temperature, °C.										
		Steel *A*	Steel *B*	Steel *C*	Steel *D*	Steel *E*	Steel *F*	Steel *G*	Steel *J*	Steel *K*	Steel *L*	Steel *M*
Fracture Appearance Criterion												
Slow notch bend test	Temp. for 32 mm. fibre below notch	+29	−48	−27	+ 4	−15	−31	+28	−42	+42	+ 2	−44
Check test					+ 4	−16	−33	+27	−51	+49	+ 6	−40
V-notch Charpy test	Temp. for 50% fibrous fracture	+30	−25	−19	+29	−14	−12	+33	−16	+36	+ 4	−23
Check Test I		+36	− 9	− 7	+24	−12	−17*	(+28)	(+10)			
Check Test II		+27	−17	− 6	+25	−12	−16	+34	−20	+44	+ 3	−22
Repeat Test									−20		+ 5	
Ductility Criterion												
Slow notch bend test	Temp. for 6 mm. deflection at max. load	+ 5	−47	−52	−11	−26	−68	+ 2	−60	+13	−33	−75
Check Test					− 6	−20	< −55	(+10)	< −70	(<+20)		
V-notch Charpy test	Temp. for energy absorption of 15 ft. lb.	−11	−35	−45	+ 4	−25	−59	+ 3	−62	0	−44	−54
Check Test I		− 3	−29	−42	+ 3	−19	−54	− 3	−37			
Check Test II		+ 3	−27	−34	+ 9	−16	−49	+ 2	−59	+ 6	−26	−46
Repeat Test									−60		−32	

*Doubtful value because of scatter.
Parentheses denote that insufficient tests were made.

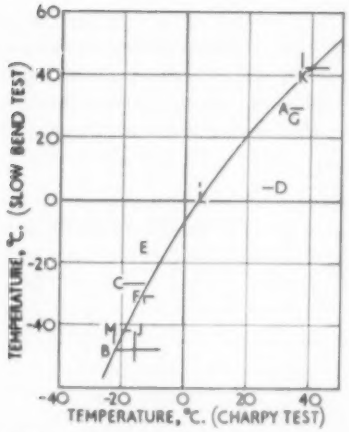

Fig. 2 Correlation of results for V-notch Charpy and slow-bend tests: fracture appearance criterion

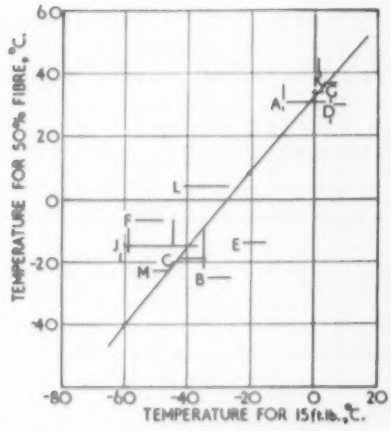

Fig. 4 Correlation of results for V-notch Charpy Test: different criteria

Fracture Appearance Criterion: Different Tests

With a single exception, all the points lie close to the smooth curve in Fig. 2. The number of samples tested was, however, too small to give this or the other curves a high degree of significance. From the slope of the line it is obvious that the slow-bend test discriminates better between steels having good notch ductility.

Steel D appears to be exceptional in some respects. The two tests differ considerably with respect to speed of loading, type of notch, and size of specimen and it is possible that Steel D, which has a high yield strength/U.T.S. ratio, responds to one or more of these variables in a manner different from that of the other samples. For instance, it may strain-harden less when a notch is pressed in it.

Ductility Criterion: Different Tests

From Fig. 3 it appears that employing the ductility criterion the slow-bend and V-notch Charpy tests classify steels in a similar manner, although Steel D is again an exception. The discriminating power of the two tests is comparable.

V-Notch Charpy Test: Different Criteria

Figure 4 shows that, while the fracture-appearance criterion and the ductility criterion grade the steels in more or less the same way, the scatter of the results is far greater than that obtained using a single type of criterion and different tests. Thus, the two criteria seem to be measuring different properties which are fairly closely related, at least in the case of the series of carbon-manganese steels.

Slow-Bend Test: Different Criteria

In this case the distribution of the points makes it impossible to determine the probable shape of the curve or the degree of scatter. The broken curve in Fig. 5 has been drawn with rather less curvature than might have been justified if more samples had been tested. However, there is some indication that the correlation between the two criteria, while reasonably good, is not as close as that between the results of different tests using the same type of criterion. For example, in most cases the temperature of the ductility transition is well below that of the fracture-appearance criterion,

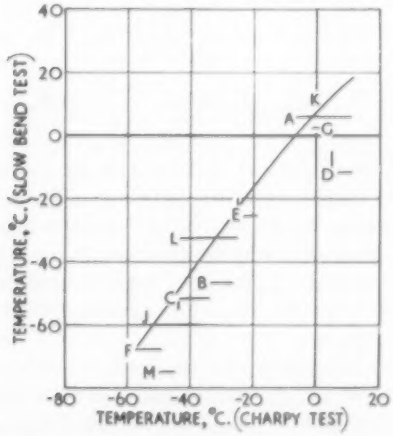

Fig. 3 Correlation of results for V-notch Charpy and slow-bend tests: ductility criterion

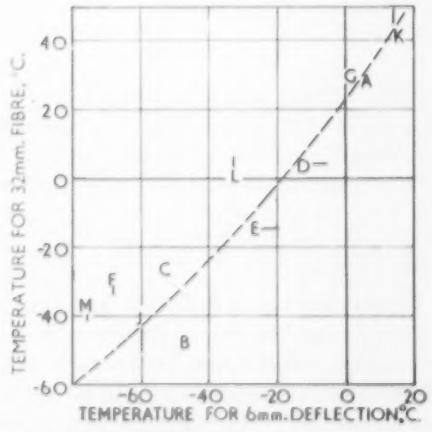

Fig. 5 Correlation of results for slow-bend test: different criteria

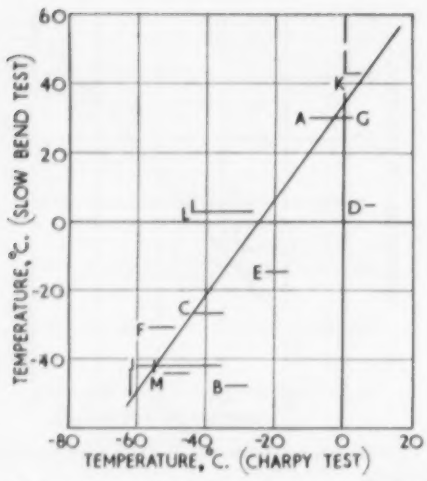

Fig. 6 Comparison of ductility criterion in slow-bend test with fracture appearance criterion in Charpy test

but in the case of Steel B the temperatures are almost the same.

Comparison of Tests as Generally Used

In Fig. 6 the fracture-appearance criterion in the slow-bend test is compared with the ductility criterion in the V-notch Charpy test. It is obvious that, while the results lie in a band, the lack of close correlation is proof that the two tests as currently used are not rating the steels in the same manner, because they are not measuring the same property. It may be pointed out that the lack of correlation cannot be accounted for by random errors in the experimental results, since a far better correlation was obtained when the two tests were compared on the basis of either of the two criteria.

Conclusions

The two tests employed generally give a similar rating to the samples of 1-in. thick carbon-manganese plate, to which the investigation has been restricted.

However, there is evidence that in the case of one steel the differences between the tests alter its rating to a significant extent. If the investigation had covered different types of steel and plates of different thicknesses it is likely that further exceptions would have been found. Where fracture appearance is to be considered, the slow-bend test is to be preferred to the V-notch Charpy test.

The two types of criteria, measuring the resistance to initiation of cleavage failure from a notch or from a traveling fibrous crack, respectively, give the same general rating to the steels tested, but there are significant differences which may well be of practical importance. Again, the differences would have been expected to be greater if steels of wider differing types had been tested.

This investigation can provide no information as to which of the two criteria is to be preferred for acceptance testing, but confirms the importance of further study of this aspect of the brittle fracture problem.

ADMIRALTY SHIP STUDIES

S. S. Ocean Vulcan and S. S. Clan Alpine Structural Trials, Admiralty Ship Welding Report No. 12

As part of an investigation of problems arising from the extended use of welding in shipbuilding, the Admiralty Ship Welding Committee sponsored full-scale experiments on the structures of actual ships. An account of these is given in a series of reports published by H.M.S.O. with the Authority of the Lords Commissioners of the Admiralty.

The Reports relating to this work are:

R6 *Ocean Vulcan* Still Water Experiments.

R7 *Clan Alpine* Still Water Experiments.

R8 *Ocean Vulcan* Sea Trials.

R9/10/11 *Ocean Vulcan* Sea Trials Detailed Analyses.

The present Report, R12*, is a discussion of the results obtained from the still-water and sea-going investigations described in detail in the above reports, R6–R11 inclusive, and states the general conclusions arrived at by the Committee from a consideration of the experiments on the dry-cargo ships *Ocean Vulcan* and *Clan Alpine*.

Certain theoretical assumptions have been necessary in framing these conclusions, and it is appreciated that later investigators may use a somewhat different approach in analyzing the results. For this reason, measurements have, where practicable, been included

* Copies of Report No. 12 may be obtained through British Information Services, 30 Rockefeller Plaza, New York 20, N. Y., Price $5.75.

in the appropriate reports.

With the publication of this Report, the series now forms a coherent whole. Each volume is largely self-contained, but cross references have been supplied where necessary in order to facilitate a complete understanding of the work.

Conclusions (Report 12)

The investigation appears to justify the following conclusions, which are in part additional to the detailed conclusions given in Reports R6, R7 and R8 of this series:

1. Provided due allowance is made for the effects of stress concentrations, local bending and the inefficiencies of panels of plating due to unfairness, the distribution of longitudinal stresses was similar in the two ships examined, and in fair agreement with simple beam theory.

2. No evidence was found to indicate that the presence of riveted seams affects the general distribution of longitudinal stress.

3. Concentrations up to about three times the nominal stress were found at structural discontinuities, with a tendency for the concentrations to be slightly greater in the welded than in the riveted ship.

4. The inefficiency of plating due to unfairness had the effect of reducing the effective moment of inertia and shifting the neutral axis, thereby modifying the stress distribution. In addition, the stresses in the vicinity of longitudinal stiffening were increased by the unfairness of the plating.

5. Apart from the eccentricities which occur at overlapped joints, the initial unfairness was found to be greater in the welded than in the riveted ship.

6. Although the heart-of-plate stresses in the unfair plating were usually lower than those which would have occurred in the same plating if it had remained plane, the surface stresses were often higher owing to the effects of local bending.

7. In the case of the welded *Ocean Vulcan* the unfairness was at some places such that the combined local bending and heart-of-plate stresses were sufficient to cause local yielding of the material, which increased the unfairness.

8. No significant difference was found between the flexural rigidities of the welded and riveted ships. In the particular cases examined, the welded ship had slightly the greater flexibility.

9. Agreement between the theoretical and observed values of deflection in the two ships examined was obtained after taking account of superstructures, local inefficiencies of unfair plating, discontinuous members and other such effects.

10. No conclusive evidence of rivet slip in the butts or seams was found within the range of bending moments and shear forces applied during the experiments, but the lower stress concentration factors found in the riveted ship suggest that rivet slip may have occurred in the vicinity of discontinuities.

11. The maximum range of vertical bending moments at sea occurs when the ship's course is normal to the wave crests and when the wave length is approximately equal to that of the ship.

12. When the ship's course is inclined to the direction of the wave advance, horizontal bending moments arise, the magnitudes of which under certain conditions may exceed those of the co-existing vertical bending moment.

13. The maximum combined effects of vertical and horizontal bending moments are such as to produce maximum stresses at the gunwale and bilge which do not exceed those due to the worst conditions for vertical bending alone. The combined effects do, however, influence the maximum stresses at other points in the girth of the ship, e.g., in the side shell plating.

14. The heart-of-plate stresses in the upper deck and outer bottom due to axial compressive forces were found to be only a small percentage of those due to maximum vertical bending moment.

15. The stresses due to torsion moments arising from wave action were found to be small compared with those due to vertical bending moment and for practical purposes may be neglected.

16. An investigation on the steepnesses of ocean waves, based on experience during the present series of trials, supplemented by oceanographical data, indicates that, for waves not greater than 800 feet long, the maximum height which can be considered to be within the bounds of practical probability can be expressed by the formula:

$$h = 21.5\left(1 - e^{-\frac{l}{200}}\right) + \frac{l}{33}$$

where h is the height of the wave and l is its length, in feet.

17. A theoretical investigation on the ships considered, supported by the experimental evidence, indicates that, in the equations which relate the motions of a ship among waves to the resulting vertical bending moments, the dynamic terms tend to cancel each other, and only become important under conditions of resonance, which, however, are unlikely to occur under severe wave conditions.

18. For the ships considered, a reliable estimate of the vertical bending moment due to waves of any given dimensions can be obtained by assuming the ship to be in static equilibrium on a trochoidal wave, and applying the Smith Correction.

19. The effects of "slamming" or "pounding" were not extensively investigated, but the greatest longitudinal bending stresses observed at midships due to this cause were of the order of ± 1.5 tons/sq in. For the cases investigated during the experiments the slamming stress increased the maximum sagging stresses, but did not increase the maximum hogging stresses. The local stresses in the structure of the bottom forward due to slamming appeared to be severe, as indicated by damage to instruments in this vicinity.

Welded Continuous Frames and Their Components
Progress Report No. 15

FURTHER STUDIES OF WELDED CORNER CONNECTIONS

Report describes results of studies into strength, stiffness, and reserve of ductility of welded knees in rigid frames when subjected to tensile loading

A. A. TOPRAC and LYNN S. BEEDLE

ABSTRACT. A series of typical welded corner connections for structural frames were tested in a manner that would simulate a relatively infrequent form of loading—a moment loading that tends to open the connecting arms. The possibility of weld fracture is thus increased. Does this form of loading constitute a possible limitation on the application of plastic analysis to structural design? The report shows that it does not. With sound welding and suitably designed joints, the desirable strength, stiffness and reserve in ductility may be achieved; thus a satisfactory connection for welded rigid frames is assured.

Introduction

The problem being considered in this report concerns the ability of welded knees in rigid frames to meet one of the possible design requirements. If the loading on a structural frame is such that the forces tend to "open" the joint, will the connection exhibit adequate strength, stiffness and reserve of ductility?

The studies were carried out as part of a program being sponsored at Lehigh University by the American Institute of Steel Construction, American Iron and Steel Institute, Bureau of Ships, Bureau of Yards and Docks, Office of Naval Research, and Welding Research Council. Several previous progress reports[1, 2] have described the results of studies into the strength of welded continuous frames and their components with particular reference to plastic action. A portion of that program has dealt with portal frames of the type shown in Fig. 1(*a*). In particular, Reference 2 has described studies of straight, tapered and curved corner connections for these frames (Fig. 1(*b*)) tested in such a way that the joints closed under the action of the forces. This is termed "compression" loading and is shown in Fig. 1(*c*). The present report considers the case in which the forces open the joint (Fig. 1(*d*)) and is called "tension" loading.

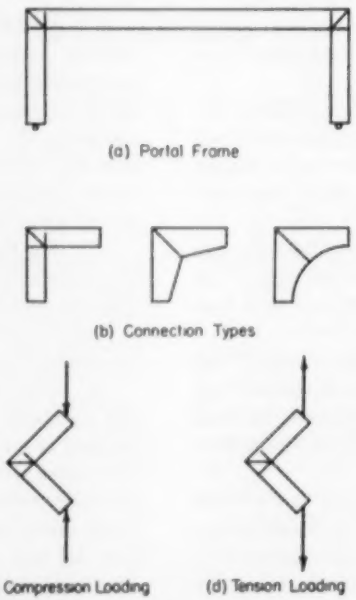

Fig. 1 Portal frame, connection types, and loading

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This work has been carried out as part of an investigation sponsored jointly by the following: American Institute of Steel Construction, American Iron and Steel Institute, Column Research Council (Advisory), Navy Department (Contract 39303), Office of Naval Research, Bureau of Ships, Bureau of Yards and Docks, and Welding Research Council.

Rigid Frame Behavior

The current studies at Lehigh University, mentioned above, together with the work at Brown University[3] and at Cambridge University in England[4] reflect the present interest in the strength of steel frames loaded beyond the elastic limit. The maximum strength of a steel frame may quickly be determined by a knowledge of the plastic behavior of components. Plastic theory assumes that, as the load increases, a plastic hinge* forms at the point of maximum moment; as load is further increased, hinges form at other critical sections until the entire structure (or a segment of it) is unable to carry more load due to the formation of plastic hinges at a sufficient number of cross sections. Application of plastic analysis to structural design results in a balanced design of a more economical frame, proportioned with less design office effort.[5]

Further discussion of plastic analysis and design may be found in the references previously cited. The important point to be kept in mind is that the ability of a steel frame to reach its computed maximum load depends upon the ability of the component parts to form plastic hinges. Some of these hinges may be caused by "tension" loading of corner connections.

Loads on Rigid Frames

A study of typical frames and their loading shows that in almost all cases, the typical loading is compression loading (joint being closed). "Tension" loading is highly unlikely in portal frames, and even if it does exist, the ability of the knee to carry high values

* A plastic hinge is characterized by rotation of a cross section through a considerable angle while the moment remains substantially constant.

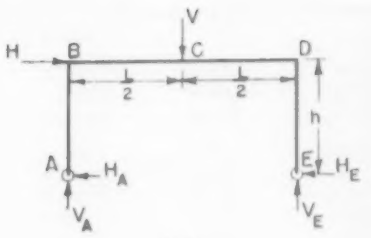
of this tension loading is not required for the development of maximum strength.

For gravity loads the joint in a portal frame tends to close under increasing loads. Due to lateral load acting alone on a frame, moments of opposite sign exist at the two knees of the frame; one of the knees is under "tension" loading and the other is under compression. However, when the two loading systems are combined, then in most structures the final moments are a high compression at the one knee and a lesser compression or modest tension at the other.

The crown of a sharply peaked gabled roof is an example of a tension-loaded connection. Heavy structural U-shaped hangers are another example, and of course blast forces could create tension loading in ordinary building structures.

A few specific examples will now be considered. In Fig. 2 a frame is shown with a span equal to twice the column height and loaded with vertical and side load. For Case I in which H is less than V (typical for wind loading), the re-entrant corner at B is in compression. Not until $H = V$ does full tension loading develop there. The formation of a tension hinge is shown at Joint B for Case III ($H > V$). Thus, the necessary condition for tension hinge action for this frame is $H \geqq V$, a value for these particular proportions that is ten times greater than that which may be expected for normal combination of wind and roof loading.

The frame of Fig. 3 has, perhaps, a more realistic ratio of span length to column height (3 to 1). The concentrated loads shown at the third points simulate uniform loading. For these proportions and for normal wind



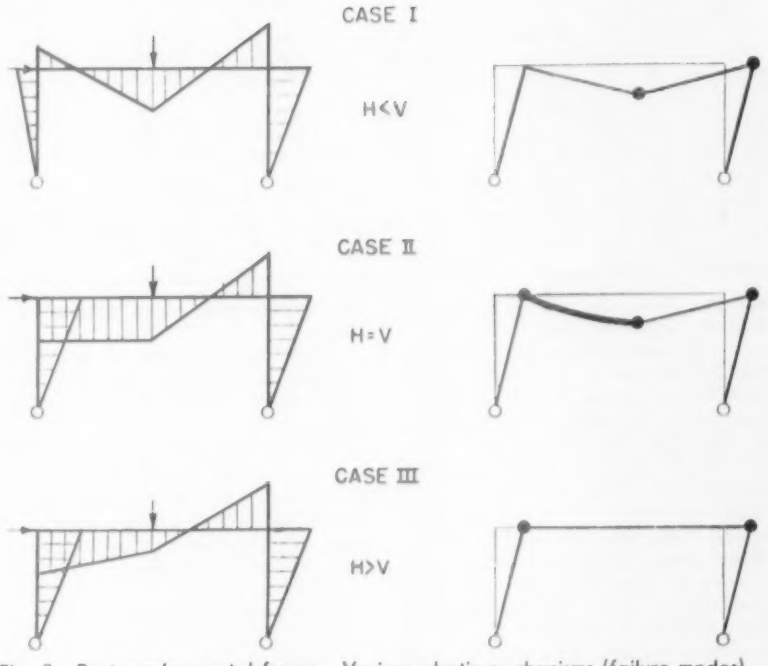


Fig. 2 Rectangular portal frame. Various plastic mechanisms (failure modes)

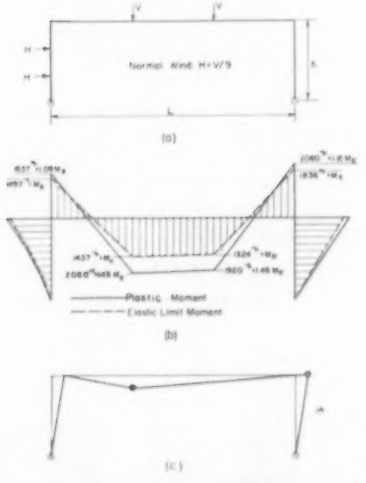


Fig. 3 Rectangular portal frame with concentrated loads. Typical moment diagrams and plastic mechanism

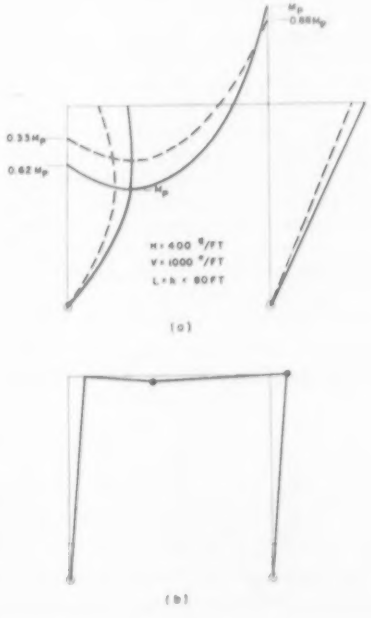


Fig. 4 (Left) Rectangular portal frame. Typical moment diagrams due to uniformly distributed loads

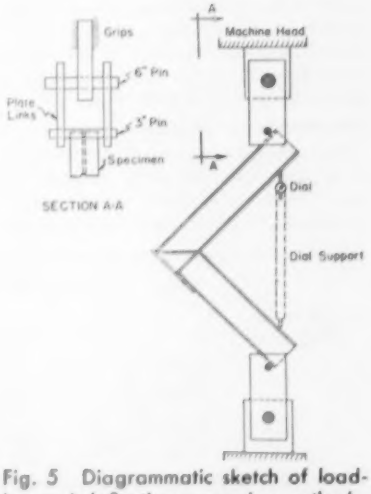
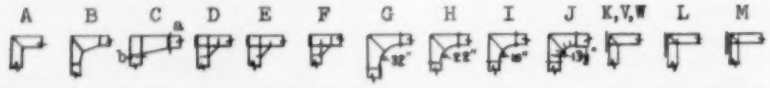


Fig. 5 Diagrammatic sketch of loading and deflection measuring method

Table 1—Test Program

Connections	*Type*	*Where tested*	*Type of test*	*Prior condition*	*Lateral support*	*Material designation*
A	Straight	Lehigh	Tension	Tested in compression	No	I
B	Tapered	Lehigh	Tension	Tested in compression	No	I
C	Tapered	Lehigh	Tension	Tested in compression	No	I
D	Tapered	Lehigh	Tension	Tested in compression	No	I
E	Tapered	Lehigh	Tension	Tested in compression	No	I
F	Tapered	Lehigh	Tension	Tested in compression	No	I
G	Curved	Lehigh	Tension	Tested in compression	No	I
H	Curved	Lehigh	Tension	Tested in compression	No	I
I	Curved	Lehigh	Tension	Tested in compression	No	I
J	Curved	Lehigh	Tension	Tested in compression	No	I
K	Straight	Lehigh	Tension	Tested in compression	No	I
L	Straight	Lehigh	Tension	Tested in compression	No	I
M	Straight	Lehigh	Tension	Tested in compression	No	I
V_c	Straight	Texas	Compression	Prime	Yes	II
V	Straight	Texas	Tension	Tested in compression	No	II
W	Straight	Texas	Tension	Prime	Yes	II



and roof loads, the ratio of horizontal load, H, to vertical load, V, is about 1 to 9. The moment diagram is shown in Fig. 3(*b*) at first yield (dotted) and at the ultimate load (solid). For the latter case the plastic mechanism is as shown in Fig. 3(*c*). For normal wind load the windward corner is still loaded in compression. A tension hinge will not form until $H/V = 1.5$, or in other words, until the side load is nearly fifteen times that normally due to wind!

Even for the rather unusual frame proportions shown in Fig. 4, the windward corner is subjected to only a moderate tension. From the bending moment diagrams of this frame it is apparent that the second plastic hinge will occur in the beam away from the knee under "tension."

Although the occurrence of plastic "tension" loading in structures is improbable, a few tests are desirable because of the special cases already mentioned in which the attainment of maximum plastic strength of the structure depends upon proper performance of knees loaded in tension.

Requirements for Connections

The general requirements imposed on continuous connections by implied or stated assumptions have been discussed previously.[1] The basic requirements for connections to resist "tension" are the same:

"(*a*) The knee must be capable of resisting at the corner the full plastic moment, M_p, of the rolled sections joined.

"(*b*) For straight knees the stiffness (or 'rigidity') should be at least as great as that of an equivalent length of the rolled sections joined. Depending upon the proportions of the frame and the deflection limitations, additional flexibility in the knee may not be objectionable so long as requirement (*a*) is satisfied within the limit established in (*c*) below.

"(*c*) The knee may be required to absorb further rotations at the near-maximum moments after reaching the plastic hinge condition. This property has been termed 'rotation capacity.' The precise requirement depends on the degree of restraint, the loading, and the length-depth ratio of the portal beam.

"The above requirements may be summarized for a square knee by stating that it must be as stiff and as strong in bending as an equivalent length of rolled section, with adequate rotation capacity as governed by degree of restraint, loading and proportions of members."

Tension at the re-entrant corner of the knee imposes a more severe requirement on the performance of the welds at that point because combined stresses in tension are present. Whereas under compression it would be expected that the strength of the knee would be limited by instability, the limit of tension loading might be the onset of weld fracture.

Purpose and Scope

With the above requirements in mind, the objectives of this investigation were the following:

(*a*) To obtain information on the strengths and rigidities of various types of knees when loaded in tension.

(*b*) To compare the results with those obtained in the previous compression tests.[2]

(*c*) To investigate whether or not weld failure would be a limitation in the design of knees when subjected to tension loadings.

The previous analyses[2] for elastic-limit strength, for deformation in the elastic range, and for plastic moment capacity are as valid for tension loading as they are for compression.

Description of Tests

The following is a short description

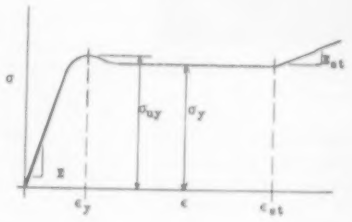
Table 2—Section Properties of Test Specimens (8B13)

Material designation		*d, in.*	*b, in.*	*w, in.*	*t, in.*	*A, in.²*	I_x, *in.⁴*	S_x, *in.³*	Z_x, *in.³*
	Handbook	8.00	4.000	0.230	0.254	3.83	39.5	9.88	11.35*
I	Measured	8.063	4.031	0.237	0.266	3.993	42.07	10.42	12.006
	% variation	+0.788	+0.775	+3.04	+4.73	+4.26	+0.651	+5.47	+5.78
II	Measured	8.07	4.06	0.231	0.257	3.96	42.1	10.44	11.95
	% variation	+0.875	+1.50	+0.435	+1.18	+3.39	+6.58	+5.68	+5.28

* Z_x, computed from properties of split tees, equals twice the area of the tee times the distance from stem to centroid.

Table 3—Summary of Coupon Test Results

Coupon	Type of test	Upper yield point, σ_{uy} psi	Yield stress level, σ_y psi	Elastic strain, ϵ_y in./in.	Plastic strain, ϵ_{st} in./in.	Strain hardening modulus, E_{st} psi
8B13 Shape, material designation I* (Lehigh)						
A1-1	Tension	46,600	45,400	0.0021	0.0170	...
A1-2	Tension	55,300	51,300	0.0019	0.0171	...
A2-1	Tension	43,700	42,600	0.00210	0.0165	...
A2-2	Tension	50,300	49,700	0.00195	...	...
	Web avg.	49,000	47,200	0.0020	0.0169	...
A1-3	Tension	41,500	41,300	0.00145	...	...
A1-4	Tension	43,300	42,200	0.00321	...	...
A2-3	Tension	43,300	43,200	0.00190	...	...
A2-4	Tension	42,600	42,600	0.004	...	...
B-1	Tension	40,100	40,100	0.0037	0.0181	431,000
B-2	Tension	41,600	41,300	0.0027	0.0232	385,000
B-3	Tension	41,600	41,600	0.0017	0.0247	594,000
	Flange avg.	42,000	41,800	0.0027	0.0220	470,000
Mill report:	Tension	44,470	Tensile strength	66,260 psi		
8B13 Shape, material designation II† (Texas)						
A_4	Tension	54,400				
A_5	Tension	47,700				
B_4	Tension	53,500				
	Web avg.	51,900				
A_1	Tension	45,800				
A_2	Tension	43,800				
A_3	Tension	47,900				
B_1	Tension	47,000				
B_2	Tension	43,800				
B_3	Tension	45,500				
	Flange avg.	45,600				
Mill report:	Not available					



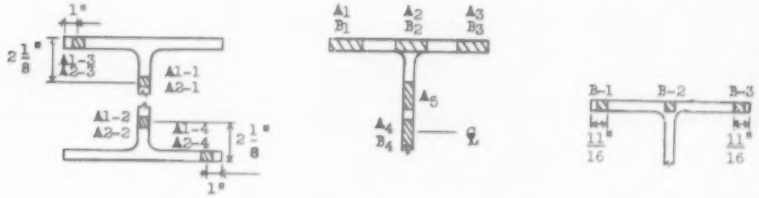
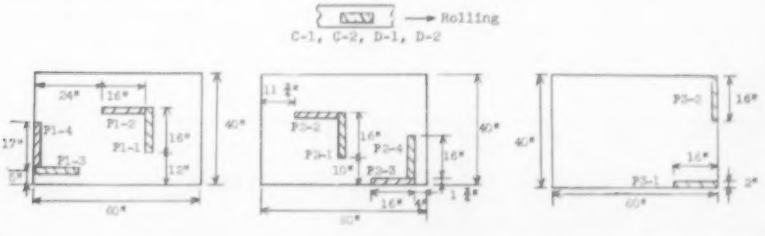


Plate material, material designation I* (Lehigh)						
P1-1	Tension	35,700	32,400	0.00128	0.0200	472,000
P1-2	Tension	33,600	32,800	0.00126	0.0179	560,000
P1-3	Tension	32,700	32,300	0.00100	0.0180	510,000
P1-4	Tension	33,800	33,200	0.00107	0.0200	465,000
P2-1	Tension	42,700	42,400	0.00180	0.0118	643,000
P2-2	Tension	41,300	40,800	0.00180	0.0185	1,130,000
P2-3	Tension	43,700	42,300	0.00130	0.0185	417,000
P2-4	Tension	44,100	43,300	0.00205	0.0197	728,000
P3-1	Tension	46,700	46,200	0.00260	0.0188	436,000
P3-2	Tension	46,500	45,600	0.00155	0.0195	506,000
C-1	Tension	38,600	38,600	0.0025	0.0168	560,000
C-2	Tension	40,200	39,500	0.0015	0.0210	546,000
D-1	Tension	36,700	35,000	0.0020	0.0162	893,000
D-2	Tension	37,100	35,500	0.0024	0.0160	606,000
Average of all plate material		39,500	38,500	0.00172	0.0180	605,000
Mill report:	Not available.					



* I, Heat No. 34Y532.
† II, Heat No. unknown.

Fig. 6 Typical test setup (Connection G)

of the specimens used, the test setup, instrumentation, and test procedure.

The knees tested in this program were straight connections, tapered haunches, and curved knees. Table I summarizes the tests conducted. Specimens A to M are the same specimens that were tested in compression as described in Reference 2 and as shown in Figs. 8 and 9 therein. These specimens were tested in tension, without being straightened after the prior compression tests.

Since all the connections had buckled previously and were permanently deformed both locally and laterally, one would expect their behavior to be somewhat different from a prime connection. Specimens V and W (which are identical to Specimen K[2]) are prime connections that were tested in compression and tension in order to:

(*a*) determine any differences between prime and previously strained connections when tested in tension, and,

(*b*) compare the behavior of identical prime members under compression and tension loads.

Connection V was first tested in compression and then in tension, whereas Connection W was tested in tension only. To distinguish between the compression test and the subsequent tension test of the same connection V, the compression test is labeled as V_c and the tension test as V. The prime tension test is labeled W.

All connections were proportioned to join two 8B13 rolled shapes. Since there were two sets of tests (A–M and V_c, V and W), there were two lots of material (designated I and II in Table 1). Average section properties for the two lots of 8B13 shapes are shown in Table 2.

The results of the physical property tests are shown in Table 3. These were standard tension tests carried out at a slow laboratory strain rate. Dimensions of the coupons were determined with the aid of a micrometer.

Connections A to M were tested at Lehigh University in an 800,000-lb screw-type machine. The specimens were set with legs at 45 deg with the horizontal and loaded through interchangeable loading fixtures bolted at each end of the specimen. The loads were transmitted through a 3-in. pin welded to the loading fixture to a pair of plate links with $3^1/_8$- and $6^1/_8$-in. holes. A 6-in. pin was secured to each head of

Fig. 8 Connection W at end of test

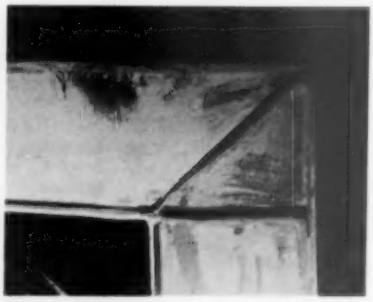


Fig. 9 Connection V at end of test

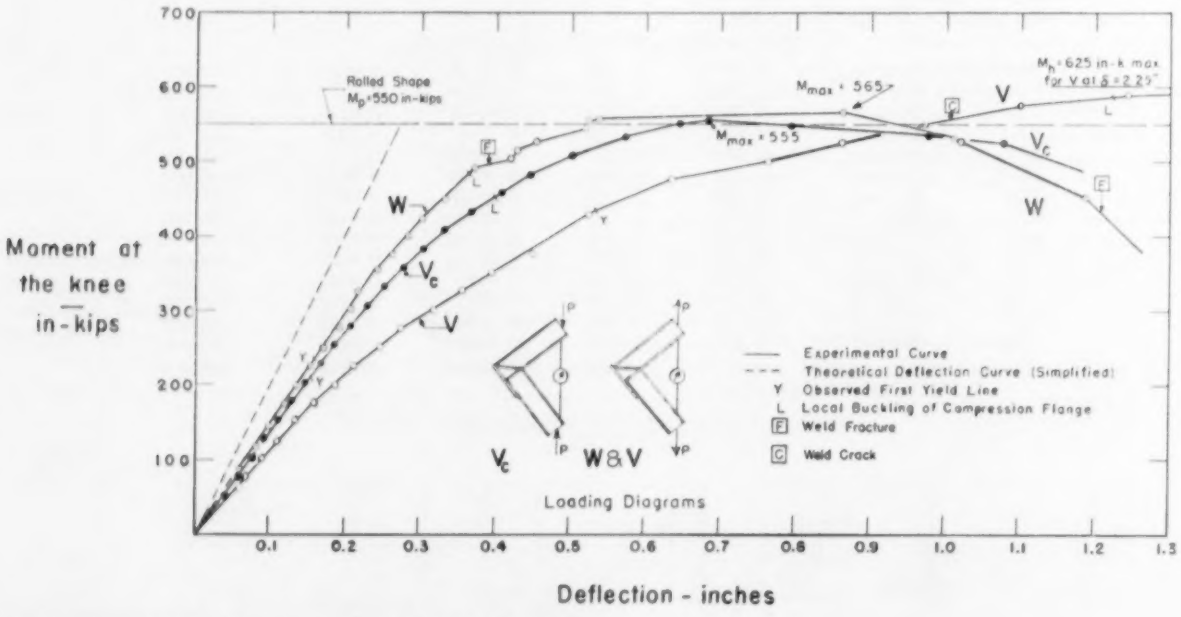


Fig. 7 Moment-deflection curves. Connections Vc, V and W

the machine to pull the specimens through the links. Figure 5 is a diagrammatic sketch of the links and the deflection dial. Figure 6 shows the links and a specimen after testing. No lateral support was provided to the specimens tested at Lehigh.

Identical experimental test setups were used for Connections V and W which were tested at the University of Texas in a 400,000-lb screw-type machine. For specimen V_c, tested in compression, the test setup is the same as that described in a prior paper.[6] Specimens V_c and W (tested in compression and in tension, respectively) were laterally supported by two pairs of flexible bars which were anchored to rigid supports furnished by two 8WF17 beams clamped to the outside of the testing machine columns at the level of the knee. Specimen V (which had already been tested in compression) was tested in tension without lateral supports.

The tests were carried out under static loading conditions at room temperature. An Ames dial gage was used to measure deflection between the arms of the connection specimens A to M and V (see Fig. 5). For Connections V and W both deflection and corner rotation data were taken. The specimens were whitewashed to reveal the flaking of the mill scale when yielding occurred.

The usual practice was to apply loads in 2-kip increments in the elastic range. This increment was decreased when yielding commenced. Beyond the elastic limit "plastic creep" occurred and therefore deformation gage readings were not taken until the connection had stabilized.

In certain cases, the test setup was somewhat crude. The use of lateral support was generally abandoned; if lateral support had been provided, the strength of the connections probably would have increased. However, it was considered that should the tests indicate satisfactory performance when tested in this simple manner, the procedure would be justified since compression loading is the more usual and critical case.

Test Results and Discussion

The results of the tests are shown in Figs. 7 to 21 and are summarized in Table 4 and in Fig. 22. The data have been arranged primarily according to connection type. Figures 7 to 12 cover the straight connections. Figs. 13 to 16 show the results of tests on the tapered haunches, and Figs. 19 to 21 include the curved knees.

Straight Connections

Connections V_c, V, W. In Fig. 7 the curves of moment at the knee vs. deflection measured across the assembly are given for specimens V_c, W and V. These are all of the same type with web stiffener omitted over the column flange. The tests were carried out at Texas to supplement the prior Lehigh tests A to M. A simplified theoretical deflection curve is also drawn, based on methods already developed in Part II of Reference 2.

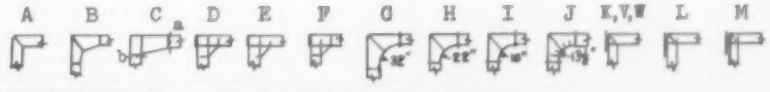
Comparison of the prime compression test (V_c) with the prime tension test (W) shows almost identical behavior. The strengths are substantially the same (555 and 565 in.-kips). The tension test is only slightly stiffer than the compression test and even this small difference probably would have disappeared had the moment values been corrected for change in distance from the line of force to the center of the knee as the specimen deflected. Both V_c and W were somewhat more flexible than the simple theory predicts. The moment at the knee is obtained by multiplying the load, P, by the perpendicular distance measured from the center of the knee (intersection of center of gravity lines of column and girder) to

Table 4—Test Results

Connection	Computed initial yield moment, $M_{h(i)}$	Tensile vs. compression strength: Tensile strength, $M_{h(t)}$	Compressive strength, $M_{h(c)}$	M_{bt} ratio tension/compression	Fracture strength (1st fracture): Nature* of fracture	Moment at fracture, $M_{h(F)}$	Ratio $M_{h(t)}/M_{h(F)}$	Weld quality
			Straight connections					
A	454	486	548	0.89	Fracture	361	1.34	Poor
K	454	613	560	1.09	Fracture	609	1.00	Fair
L	454	686	624	1.10	Fracture	686	1.00	Fair
M	454	674	576	1.17	Fracture	674	1.00	Fair
V, V_c	476	(V) 625	(V_c) 555	1.13	Crack	552	1.13	...
W	476	565	555	1.02	Fracture	506	1.12	Fair
Avg. (K to W)		634	574	1.11				
			Haunched connections (tapered)					
D	597	976	751	1.30	Fracture	960	1.02	Poor
E	597	1050	804	1.31	Crack	832	1.26	Fair
F	597	1015	844	1.20	None	..	..	Good
Avg. (D.E.F.)		1014	800	1.27				
B	750	781	728	1.07	None	..	..	..
C	524	793	720	1.10	Crack	†	..	Fair
			Curved connections					
G	970	1358	1296	1.04	None	..	..	...
H	840	1220	1228	0.99	Crack	1170	1.04	...
I	883	1169	1180	0.99	Crack	1168	1.00	...
J	620	1006	915	1.09	Crack	979	1.03	...
Avg. (G to J)				1.03				

* Crack—means a very small separation, not usually visible; did not affect strength. Fracture—means a separation that developed to the point of being visible.

† Fracture occurred after maximum load.



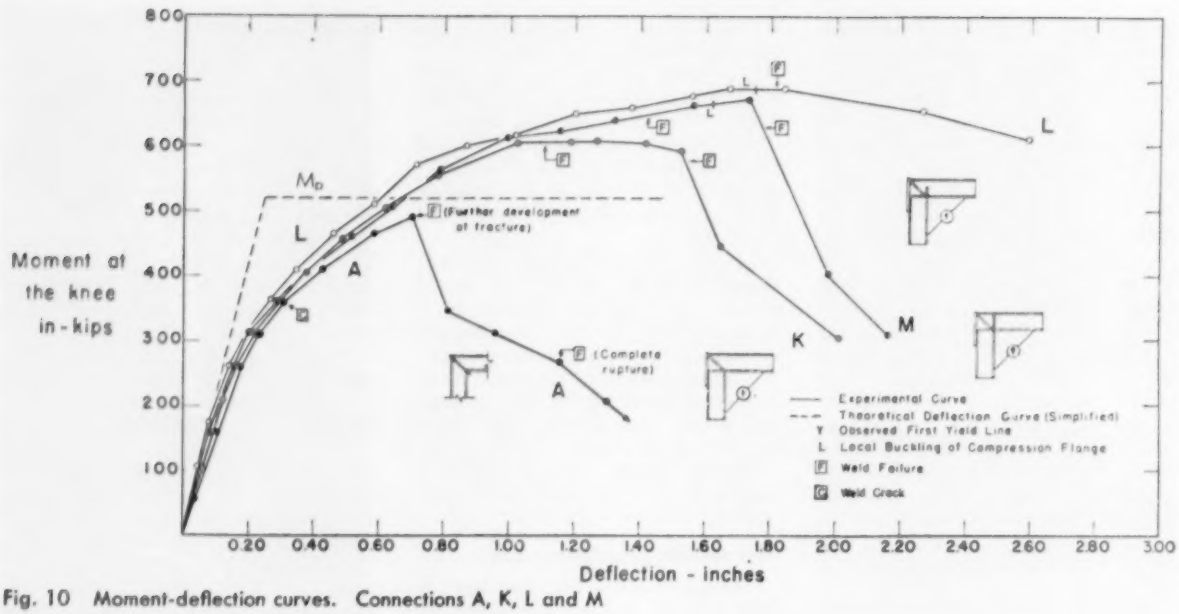


Fig. 10 Moment-deflection curves. Connections A, K, L and M

the line of force. This distance gradually becomes greater for specimens under compression loads and becomes smaller for those under tension loads.

The difference in behavior of a "prime" tension test and one tested first in compression and then in tension is shown in Fig. 7 by a comparison of V and W. Specimen V, tested in tension after having been previously tested in compression as V_c, carried a higher maximum moment (M_b = 625 in.-kips against 565 in.-kips for W), and was considerably more flexible than prime member W. The curve for Connection V departs from linearity sooner than the other two connections due to the Bauschinger effect (localized residual stresses due to the prior compression yielding). The increase in strength may be due, in part, to hardening by virtue of the prior compression.

In both Connections V and W the first weld failures* occurred at about the same moment value; but V went on to carry increased load, whereas W collapsed rather quickly. The most probable cause for this difference is better welding on V than on W. Another contributing factor might be the presence or absence of lateral support. V was not supported laterally; W was. By increasing the general stiffness of the entire assembly, fracture tendency is increased. It seems, however, that difference in weld quality is the more likely explanation.

These connections were detailed just like Connection K. By comparison with Fig. 23 of Reference 2 it will be seen that the behavior of the compression test (V_c) was almost identical to Connection K.

All three connections shown in Fig. 7 reached the computed M_p value. There was a considerable reserve of strength beyond the first weld crack.

In the figures the points of first yield (*Y*), local buckling (*L*), weld crack (*C*), and weld fracture (*F*) have been indicated by the appropriate symbols. With regard to yielding, the two prime connections show the typical behavior of local yielding at about one-third to one-half of the computed yield load. Local buckling of flange edges was observed by eye.

Weld cracks occurred in Specimens W and V. However, in the case of W, weld failure started after the initiation of local buckling. On all of the connections, weld quality left something to be desired. The connections performed so satisfactorily, however, that the effect of defective welds would not have limited the ability of a frame to carry the computed loads.

Figure 8 shows Connection W at the end of the test. One crack started at the inside column flange and propagated considerably into the web of the column; the other failure was in the diagonal stiffener attachment at the inside corner. This was the only connection to fail at the diagonal stiffener connection. The fact that yielding due to shear force occurred in the web that had been stiffened with the diagonal plate is further evidence for the need of this element.

Figure 9 shows Connection V at the end of the test. The extensive yield in the web and local buckling of the exterior flange shows that the fracture did not limit the carrying capacity of the knee. Figure 24 shows by sketch the location of weld fractures.

Connections A, K, L, M. Figure 10 gives the moment-deflection curves for the four square knees A, K, L and M. For these specimens (as well as those that follow) the moment arms used were corrected for the change in distance between the center of the knee and the line of applied forces due to deformation. Table 4 summarizes the strength of the four knees.

Figure 10 shows that the behavior of the four connections was similar up to the point of fracture. By comparison with the theoretical curve it is seen that no fracture occurred at a moment less than the plastic hinge moment, M_p, except for Connection A (the one involving the most difficult weld). The strength in tension was greater than the compressive strength (excepting A). The maximum strength of K compares rather well with its companion, V.

The best characteristics were exhibited by Connection L, although there is little difference from M. Yielding at relatively low loads due to the Bauschinger effect is also in evidence in these tests.

Local buckling (see "L" in Fig. 10 on the curves for Connections L and M) is delayed in comparison with the compression tests. Figure 23 indicates why local buckling is more critical for compression than for tension. Under compression loading (Fig. 23*a*) local buckling would occur at lower moments because compression flexural strains are added to direct strains in compression; under tension loading (Fig. 23*b*) the compression flexural strain is *reduced* by the superimposed tensile direct strain. Local buckling should therefore occur at a

* As will be discussed later, in some cases weld cracks were scarcely visible and did not alter the behavior; in others they progressed and led to final collapse.

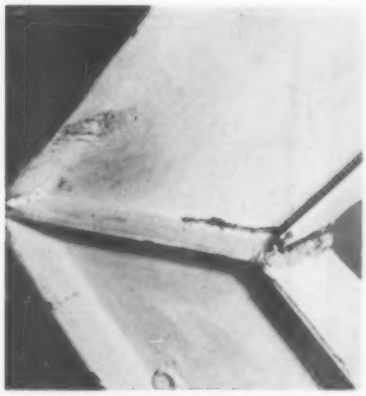


Fig. 11 Connection A. Note crack at re-entrant corner

Fig. 12 Connection K. Note crack at re-entrant corner

Table 5—Notes on Weld Fractures

Connection	*Type of fracture*	*Nature of weld failure*
A	Exterior: Poor penetration, "shear-tear" failure. Interior: Failure started at one side where there was poor penetration; progressed to the other side of flange as a ductile (shear) tear. Web: "Poor penetration" type of failure; web pulled out from the weld.	Fracture
B	No crack.	None
C	Very poor weld; crack formed but was no longer visible after end of test; weld is irregular and conducive of fracture due to stress concentration.	Crack
D	The first tear (outside) involved a shear failure in an undersized weld; back-up pass was never deposited; failure in web attachment started in shear, shifted to "shear-tear" (poor penetration), and back to shear; poor weld at the opposite corner; the failure is also ductile with local necking in evidence.	Fracture
E	No cracks visible at end of test; appearance of both critical welds is poor. Much undercutting.	Crack
F	Appearance is the best of the series; no fractures were observed; some undercutting.	None
G	None	None
H	Crack not visible; audible during test.	Crack
I	Cracks visible during test but "closed up" at end of test.	Crack
J	Cracks at junction of radial stiffener and inner flange; "closed up" at end of test.	Crack
K	Penetration pull-out (below the fusion line); shear failure in weld as the secondary crack.	Fracture
L	Weld has better appearance than Connection K; more shear failure, but considerable penetration pull-out below fusion line—flange.	Fracture
M	Similar behavior to L; some penetration failure at web; welds only fair; some undercutting.	Fracture
V_c	None	None
V	Crack at bottom of diagonal stiffener weld on both sides of web and crack at top of inside column flange.	Crack
W	Crack at bottom of diagonal stiffener weld on both sides of web and crack at top of inside column flange.	Fracture

higher resultant moment when the loading is in tension. The table in Fig. 23c confirms this.

Figures 11 and 12 show Connections A and K at the end of the test. Cracks which developed in both connections at the re-entrant corner are visible. As was usually the case, first fracture did not cause immediate collapse. This came at higher load as the crack opened up and propagated to the web of the beam. As summarized in Table 4, and as described in more detail in Table 5, the weld quality was at best only fair in all of the connections. There was poor penetration and there were numerous inclusions. With regard to Connection K (Fig. 12) the external weld was good; but the penetration was poor on the weld at the opposite side. Performance of welds is discussed in a later section of the report.

Summarizing the behavior of these straight connections, if high "tension" load is expected, then Connection A seems the least desirable detail of the group. The rest of the connections exhibit no limitation to plastic design of ordinary structures due to the fractures that subsequently occurred.

Tapered Haunches

Connections D, E, F. Figure 13 shows the moment-deflection curves for

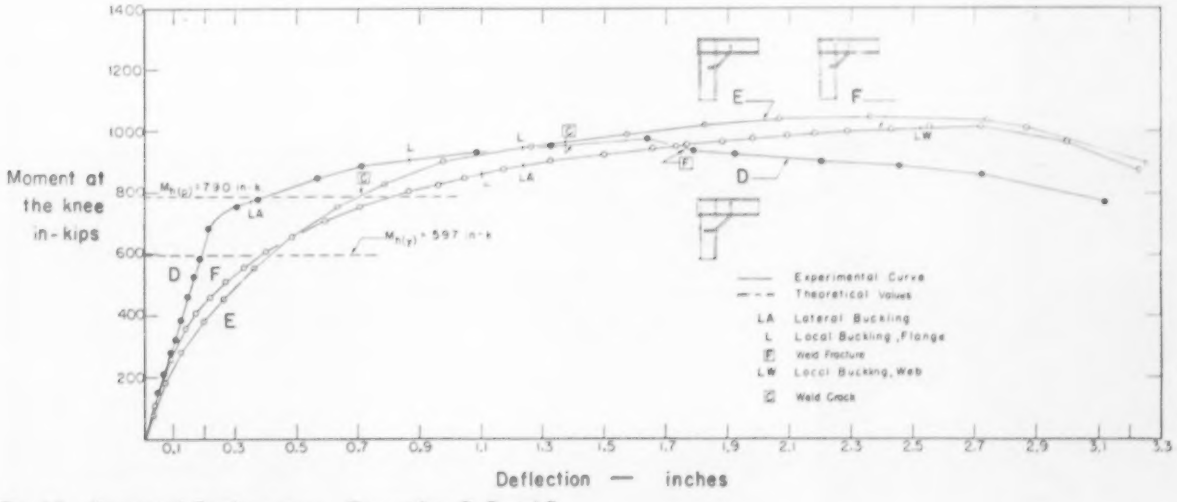


Fig. 13 Moment-deflection curves. Connections D, E and F

Fig. 14 In Connection D weld failure (see Fig. 24) and local buckling were present at end of test

Fig. 15 Connection F at end of test (no weld failure)

Fig. 17 Connection B at end of test

these three connections. Concerning the theoretical values, the haunch moment at first yield, $M_{h(y)}$, includes the effect of axial thrust. The haunch moment at plastic yield of the rolled section, $M_{h(p)}$, does not.

As shown in Table 4, the strength in tension was considerably greater than the strength in compression. On the average, the increase amounted to more than 25%. The weld quality seemed somewhat better (Table 5). No fractures occurred below the yield load nor below $M_{h(p)}$; thus there is no limitation to plastic design due to these fractures. Connection F did not fracture at all.

In Fig. 13, the moment value at observed lateral buckling is designated by "LA." Actually in any given test it is often difficult to distinguish between local and lateral buckling. Does local buckling cause lateral buckling or is local crippling the result of lateral deformation? Both lead to collapse, and in these specimens, buckling of one type or the other preceded fracture.

Due to the fact that the "notch" is less severe in the "45-deg bracket" type than in the straight connections, fracture tendency is less pronounced. There was no sudden collapse due to weld failures in these specimens, the maximum load always being greater than the cracking load.

Figure 14 shows the appearance of Connection D at the end of the test. Connections E and F failed primarily by local and lateral buckling; Fig. 15 shows Connection F at the end of the test.

Connections B and C. Figure 16 shows the moment vs. deflection curves for haunched Connections B and C. As with the previously discussed connections, the strength in tension was greater than the compression strength (Table 4). Connection C developed a moment greater than that necessary to meet

Fig. 18 Connection C failed by buckling in the column outside the knee

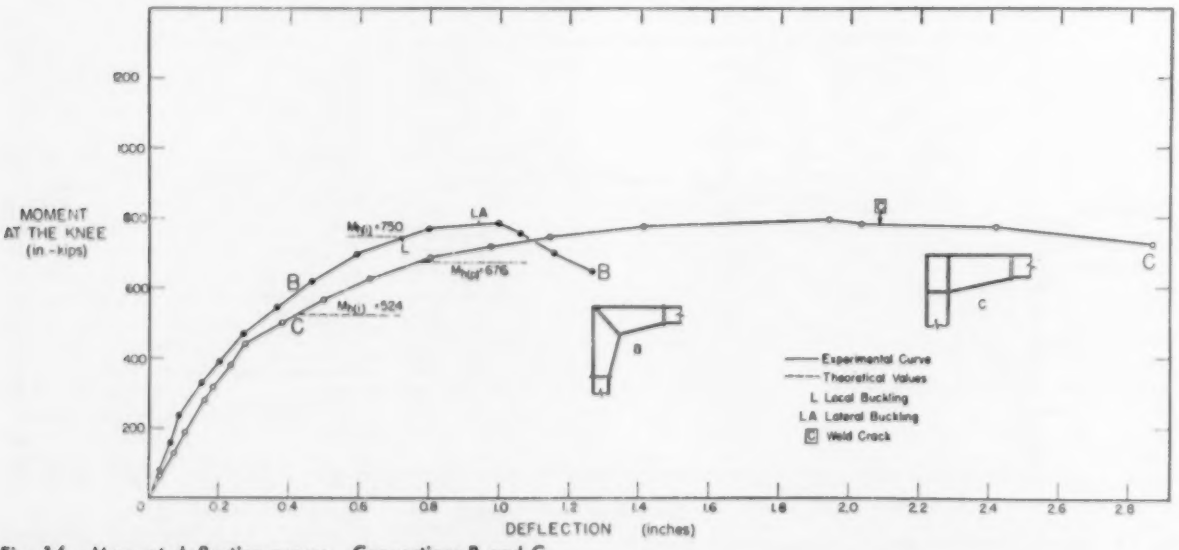


Fig. 16 Moment-deflection curves. Connections B and C

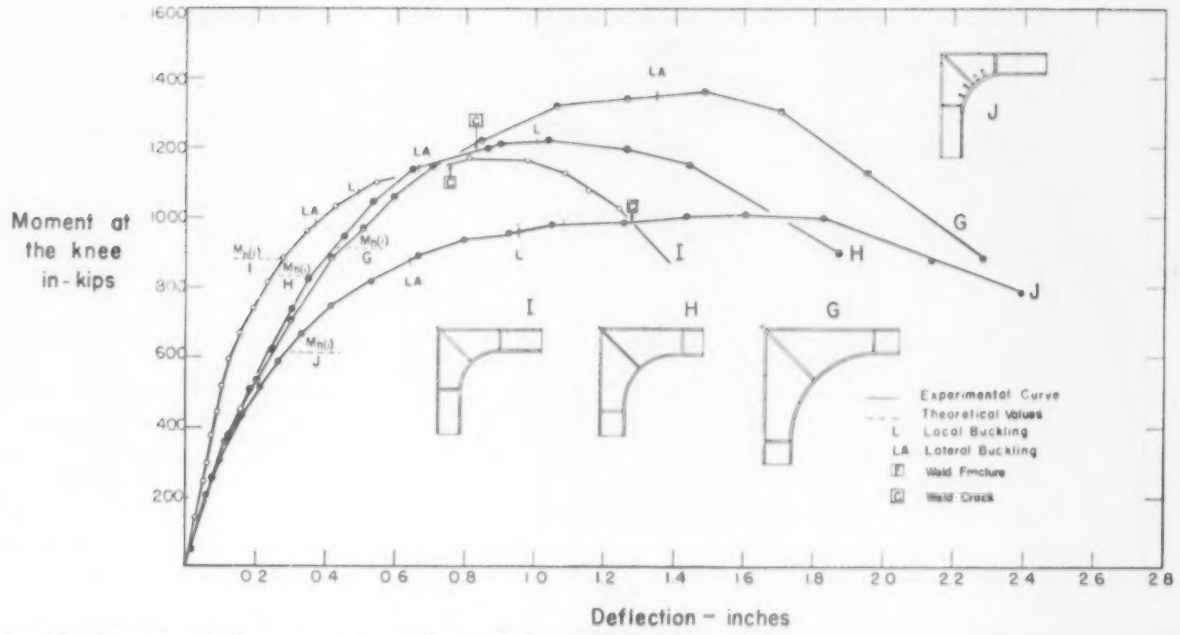


Fig. 19 Moment-deflection curves. Connections G, H, I, and J

plastic hinge requirements. Although the strength of Connection B exceeded the computed yield value, it did not quite reach the plastic moment value; it did not fracture.

Both connections failed by local and lateral buckling of the outer (compression) flange. The weld crack did not affect the strength of Connection C since buckling preceded it. Figures 17 and 18 show the connections after test.

Curved Knees (Specimens G, H, I, J)

Figure 19 gives the moment-deflection curves for these four connections. The comparison in Table 4 shows that the curved knees developed strength in tension just about equal to those in the prior compression tests (within 4% for G, H and I). There is a most adequate reserve of strength above first yield. Comparison of Fig. 19 with Fig. 44 of Reference 2 indicates that the deformation behavior in tension was also quite similar to that in compression.

Fig. 20 Connection I

All four curved knees failed by local and lateral buckling. Some cracks of minor importance developed in H and I at the end of the knees where the rolled sections were welded to the built-up portions, and in J at the radial stiffeners; but all these weld "failures" were insignificant and did not contribute to the failure. Buckling occurred prior to fracture (in Fig. 19 see the designation "L" and "LA" to denote local and lateral buckling).

Figure 6 shows Connection G at the end of the test. The localized yielding and the lateral buckling which brought about the final collapse of this connection are evident. Figure 20 shows specimen I after failure and at the end of the test. Connection J is shown in Fig. 21.

Strength of Connections

As mentioned previously, Table 4 presents a summary of the strength of the connections tested in this series and subjected to tension loads. Figure 22 is a summary of the moment vs. deflection curves for all of the connections tested and is presented on a nondimensional basis. In every case the maximum observed haunch moment was greater than the computed yield value; as Fig. 22 shows, the reserve above first yield is more than adequate in most cases. Further, in every case except Connection A, the strength in tension was at least equal to and in most cases greater than the strength in compression (Table 4). The average increases were 11% for the straight connections, 27% for the 45-deg bracket connections, 8% for haunched connections B and C, and 3% for the curved knees.

A comparison with the computed haunch moments to give the plastic moment at the extremities of the haunch (Table 6, Part III, Ref. 2) shows that except for Connections A and B, the full plastic moment strength was developed.

The limitation on strength was either local and lateral buckling or weld fracture. The results show that the behavior of Connection A in this test is inadequate and that Connection B should be proportioned with a thicker inner flange; but otherwise neither the local buckling nor the weld fractures could be considered as a limitation on use of these knees. The necessary strength was developed prior to "failure."

Rigidity of Connections

Most of the members tested in tension exhibited nonlinear behavior at lower loads than in the previous compression

Fig. 21 Connection J

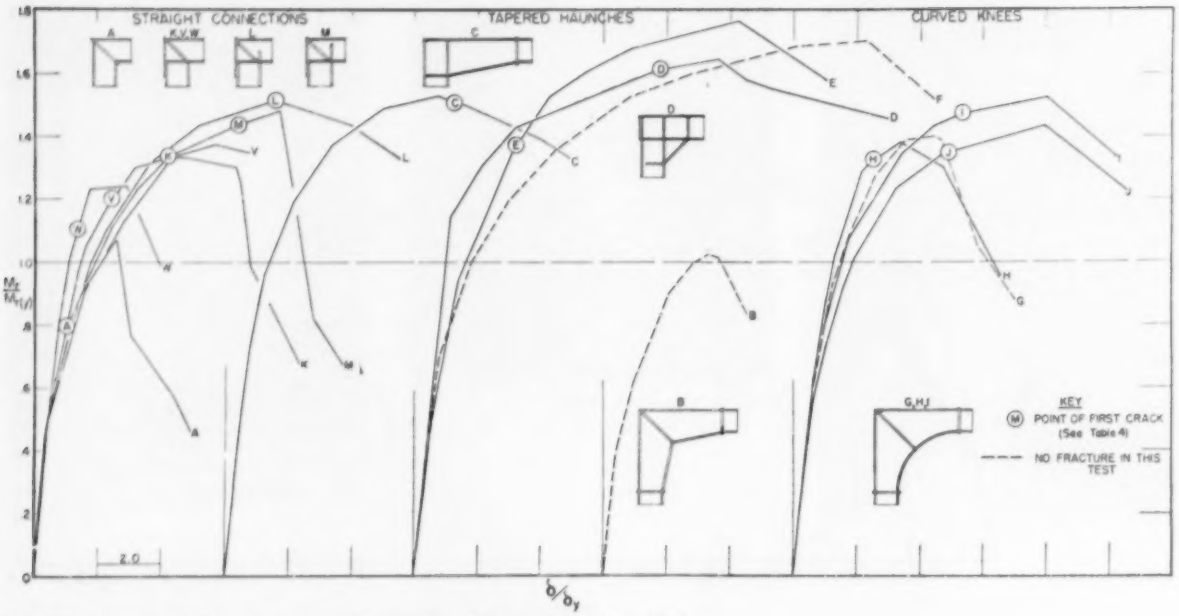


Fig. 22 Moment-deflection curves. Connections A through M, V and W

tests. This is due to the Bauschinger effect; in no way does it constitute any limitation in the use of these connections in design.

With regard to rotation capacity, the performance meets all normal design requirements. In the curved and haunched connections none is required. Some of the straight connections show little rotation capacity, but in ordinary structures rotation capacity in "tension" is not mandatory as such a hinge is usually one of the last to form.

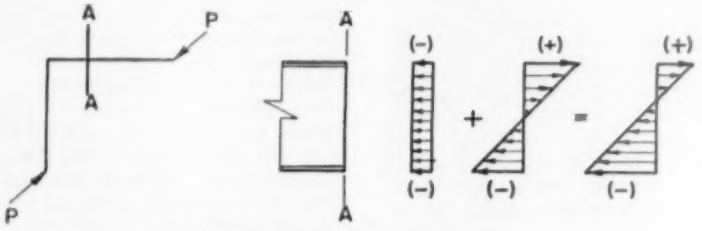
Performance of Welds

The chief difference between the tension and the compression behavior of these particular tests is that fractures of some of the welds occurred in the former. This fracture is due in part to stress concentrations and the presence of multiaxial stresses; but primarily it was due to poor welding. Table 5 summarizes observations made in connection with the welding of the various joints. With proper inspection, the usual commercially welded joints will not be deficient. The "poor welding" on these specimens resulted, in fact, from an effort to avoid laboratory precision.

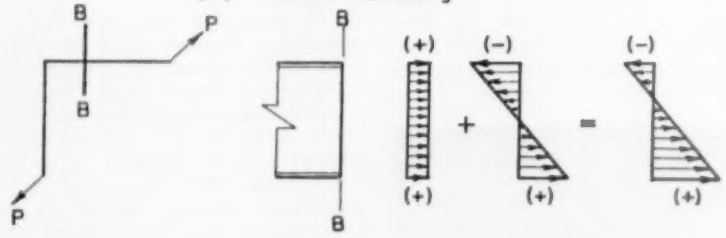
In three of the connections there were no weld failures whatever (B, F, G). In six of the connections cracks occurred (designated by "C" in some of the figures—the connections involved were V, E, C, H, I, J). In no case did these cracks develop further nor did they influence the behavior in any way. Fractures occurred in the remaining six tests (A, K, L, M, W, D). Five of these were straight connections and one (D) was a bracketed joint. Of these six joints, fracture was not accountable for the final failure of L and D (Fig. 14) because local and lateral buckling were also involved in the collapse. The sudden collapse due to fracture of A, W, K and M is evident from Fig. 22. As may be seen from Fig. 22, only Connection A fractured at a moment less than the yield moment. There is a "reserve" strength above the fracture moment in most cases.

As is clear from Table 4 and Table 5 there is a direct correlation between weld

(a) Compression Loading



(b) Tension Loading



(c) Comparison of Approximate Moments (in-k.) at Local Buckling

Type of Load	CONNECTION								
	A	K	L	M	D	E	F	V	W
Compression	520	530	590	530	710	785	760	440	(440)
Tension	—	—	685	665	910	950	860	585	485

Fig. 23 Combined stresses cause local buckling to be more critical in "compression" than "tension"

quality or soundness and the tendency to fracture. Sound welds did not fail in spite of severe stress concentrations. Poor welds led to fractures. Had all of the welds been sound, it is reasonable to suppose that *none* of the connections would have failed due to weld fracture. In those connections which did fail, the prime cause was lack of penetration. All of the failures were of the shear (ductile) type except for those cases where penetration was apparently poor.

As was mentioned above, only in the case of Connection A was weld failure a limitation in the use of the knee. In all other cases of fracture, the necessary design requirements had been achieved prior to weld failure.

More recent tests on 12- and 14-in. straight connections (to be reported upon later) have been conducted with no fractures whatever.

Summary

The following summarizes the results of this study of connections loaded in such a way that the inside, or re-entrant, corner is in tension (that is, "tension loading"):

1. The formation of hinges due to tension loading in usual engineering structures is highly unlikely (Figs. 2–4). Thus the requirements of strength and reserve ductility are not as stringent for tension connections as for those loaded in compression.
2. The stiffness of connections in tension is comparable to that in compression.
3. Except for Connection A, all of the connections were stronger in tension than in compression, even though cracks or fractures occurred in many of them (Table 4).
4. The first crack did not cause immediate collapse. In almost every case there was a reserve of strength after initiation of a crack (up to 36%).
5. With but a few exceptions the mode of failure of the connections under tension loading was similar to that observed in the compression tests. Ordinarily fractures were of less pronounced influence than the local and lateral buckling that produced final failure.
6. The weld quality on the straight knees (A, K, L, M, W, V) was generally poor, and there was a direct correlation between weld soundness and fracturing. It is reasonable to expect that had the welding been sound, none of the fractures would have occurred. In more recent tests on larger connections, no fractures whatever have occurred.
7. Only Connection A fractured at a moment less than the yield moment (Fig. 22). In spite of this fracture, the connection continued to carry moment and, in fact, exceeded the computed yield value. In most cases there is a considerable and adequate "reserve" above computed yield. There is a correlation between fracture tendency and magnitude of stress concentration.
8. These results show that, even with poor welds, plastic design of rigid frames would be no more limited by the fractures than would elastic design. Except for Connection A, neither would the fractures be a limitation to elastic design. With good quality of welding, these connection types would constitute suitable designs even for those special cases that require the formation of a tension hinge.

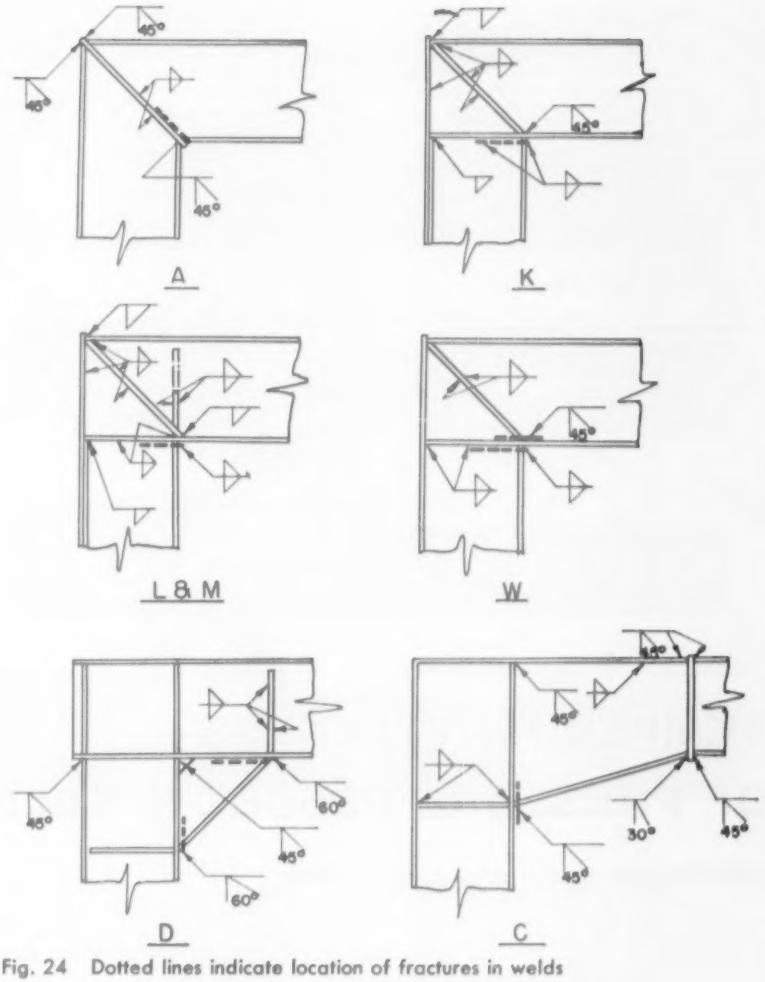


Fig. 24 Dotted lines indicate location of fractures in welds

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Nomenclature and Terminology

A	=	area of cross section
b	=	flange width
"C"	=	weld crack
d	=	depth of section
E	=	Young's modulus of elasticity
E_{st}	=	strain-hardening modulus = $\left.\frac{d\sigma}{de}\right\|_{st}$
"F"	=	weld failure
H	=	horizontal load
I	=	moment of inertia
"L"	=	local buckling
"LA"	=	lateral buckling
M	=	moment
$M_{h(c)}$	=	computed moment at which yielding commences due to normal stress
$M_{h(p)}$	=	haunch moment at plastic yield of the rolled section
$M_{h(y)}$	=	theoretical haunch moment at first yield of rolled shape
$M_{h(t)}$	=	maximum observed haunch moment
M_p	=	full plastic moment
M_s	=	moment at section joining rolled shape to knee
$M_{s(y)}$	=	computed yield moment at section joining rolled shape to knee
M_y	=	moment at which yield point is reached in flexure
S	=	section modulus, I/c
t	=	flange thickness
V	=	vertical load
w	=	web thickness
"Y"	=	first yield
Z	=	plastic modulus
δ	=	deflection of connection arms
δ_y	=	computed deflection at first yield of rolled shape
ϵ_{st}	=	strain at strain hardening
ϵ_y	=	strain at upper yield point
σ	=	normal stress
σ_{uy}	=	upper yield point
σ_y	=	yield stress level

TEMPER BRITTLENESS OF PRESSURE VESSEL STEELS

DISCUSSION BY M. A. SCHEIL AND C. B. REX

Dr. Jaffe has presented an interesting and useful study of the general problem of temper embrittlement. In addition, it is felt that the practical value of the paper is enhanced by the discussion by Mr. Blumberg.

Another rather excellent example of the temper embrittlement phenomenon occurred in forged air flasks for Navy torpedoes about the beginning of World War II. The material was a medium carbon, nickel-chromium steel, something of the order of the Krupp analysis. These air chambers had been oil quenched and tempered *and probably slow cooled in the tempering operation*. Nearly two hundred of these were in supply depots at the time of Pearl Harbor. However, a retest of one of these flasks at Providence, Rhode Island, resulted in a sudden fragmentation in the hydrostatic test. This failure caused the Navy to withdraw from service the entire quantity on hand at a particularly critical period.

A proposal was made to retemper and quench from the temper in oil to attempt to improve the metallurgical properties. The redraw temperature was 1150 °–1175° F. This procedure was completely successful permitting nearly all of the flasks to be returned to the Navy in usable condition for service.

Chemical analysis and mechanical properties of the steel were as follows:

Chemical Analysis, %

C	0.46	Ni	3.40
Mn	0.72	Cr	1.15
Si	0.15	Mo	..
P	0.02	V	0.04
S	0.04		

Mechanical Properties

	Before	*After retemper and oil quench*
Ultimate tensile strength, psi	152,000	147,000
Yield strength (0.1 % offset), psi	135,000	130,000
Elongation in 2 in., %	12	15.5
Reduction area, %	41.7	49.7
RKwl "C"	33–34	32–35
IZOD, ft-lb	1.5–3.0	28–30
Hydraulic failure, psi	3400	6000
Fracture	Fragmented and brittle	Torn and tough (no fragments)

M. A. Scheil is Director of Metallurgical Research, A. O. Smith Corp., Milwaukee, Wis., and **C. B. Rex** is Head, Materials Branch, U. S. Naval Underwater Ordnance Station, Newport, R. I.

Paper by L. D. Jaffe was published in THE WELDING JOURNAL, **34** (3), Research Suppl., 141-s to 150-s (1955).

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	Tensile Strength lbs. per sq. inch	Elongation	Hardness Rockwell 'B'	Electrical Conductivity
JACKSON	70,000	2%	70	35%
Make "B"	25-30,000	10-20%	6-7	25-30%
Make "C"	25-30,000	10-20%	10	16%

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Model AA-3.....$ 8.00
Model AA-3S.....$ 8.50

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(2) Powdered iron coating melts and becomes an integral part of the weld.

(3) The extra-heavy coating helps control arc action and allows higher currents to be used in complete safety.

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